ESSAYS ON THE ECONOMICS OF INNOVATION

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This dissertation examines the allocation of inventive ideas through the trade of patent portfolios, the measurement of inventive output and the design of mechanisms to encourage investment in research and development.

The first chapter introduces a new data set of patent portfolios traded between 1990 and 2011 consisting of 2,045 granted U.S. patents and patent applications. Combined with a random sample of all patent portfolios traded in 2005, this new data set allows for the derivation of estimates of the size of the market for patents, which is estimated at $10 billion in 2005. The average value of a traded patent is about $505,000. Patent portfolios acquired by patent assertion entities (PAEs)-companies that purchase patents without the intention of using the underlying technology internally, but instead focus on the assertion of the purchased patents against manufacturers already using the technology-account for about $380 million or 3.8 percent of the total market. The litigation rate for traded patents is 2.3 percent during the acquiring entity's term of ownership. Patents acquired by PAEs do not have an increased likelihood of being litigated compared to other traded patents.

The second chapter examines field trial data for patented corn hybrids to quantify the relationship between patents, citations, and the magnitude of inventive output. Field trial data for 256 corn hybrids patented between 1986 and 2005 suggest that most patented corn hybrids do not improve significantly on prior art: 58 percent of patented hybrids produce less corn than existing hy-

brids. However, there exists a relationship between the number of subsequently granted U.S. patents citing a patent in our data and the magnitude of inventive output: A 10 percentage point increase in yields is associated with 1.9 additional citations.

The third chapter examines the optimal design of mechanisms of awarding patents and prizes under different information environments. Using the full information environment as the benchmark, I analyze the case in which information about the value of an innovation is either (i) only observed by the innovating firm or (ii) observed by the innovating firm and another firm in the same industry. In general, the social planner awards prizes whenever these are available as a policy instrument. While there exist mechanisms to reveal the social value of an innovation under the private information environment, truth telling can only be achieved by providing some patent protection in most of the considered cases. The social surplus is then lower than the full information benchmark. When market information about the social value of an innovation is available from a competitor, the social planner can achieve the same level of social surplus as in the full information benchmark.

BIOGRAPHICAL SKETCH

Joerg Ohmstedt was born in Bremen (Germany) on July 2, 1981. He graduated from Kippenberg-Gymnasium, Bremen (Germany), in 2001 and entered University of Cologne (Germany). After his graduation in 2006, he came to the United States as a Fulbright scholar to pursue doctoral studies in economics at Cornell University. He earned a Master of Arts in economics from Cornell University and will be awarded a Doctor of Philosophy in economics from Cornell University in May 2012.

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CHAPTER 1

THE MARKET FOR INTELLECTUAL PROPERTY: EVIDENCE FROM TRADED PATENT PORTFOLIOS

1.1 Introduction

The market for intellectual property has been growing significantly over the last two decades (Arora and Gambardella, 2010; Chesbrough, 2006).[1] Accompanying the growing importance, there is increased debate among academics, policy makers and the business audience, whether the benefit of promoting the efficient allocation of technology outweighs the drawbacks of an increased amount of litigation and rent seeking behavior of patent assertion entities (PAEs)-companies that purchase patents without the intention of using the underlying technology internally, but instead focus on the assertion of these purchased patents against manufacturers already using the technology.[2]

The possibility to trade patents allows for the division of labor between small firms which specialize in generating inventions and large firms which specialize in the commercialization of these inventions (Holmstrom, 1989; Gans and Stern, 2000; Gans et al., 2002). Similarly, companies might benefit from trading technology due to vertical specialization and comparative advantages: while some companies have a comparative advantage in research, others have a comparative advantage in manufacturing or marketing (Teece, 1986; Arora et al., 2001;

[1]The existence of a market for intellectual property is not a recent phenomenon. Lamoreaux and Sokoloff (1996, 1999, and 2001) provide an overview of the market for patents in the nineteenth and early twentieth centuries.

[2]The term 'Patent Assertion Entity' (PAE) was put forward by the Federal Trade Commission (FTC) in its recent report on the development of the intellectual property marketplace (FTC, 2011). Alternatively, the terms 'Non-Operating Company', 'Non-Practicing Entity' (NPE) or 'Patent Troll' are commonly used.

Arora and Ceccagnoli, 2006). The management literature advances the idea of Open Innovation: companies should allow externally developed inventions being brought into the firm and try to sell or license internally generated inventions that are under- or unutilized to other companies (Chesbrough, 2003). The possibility to trade patents also provides a salvage value for failed innovators and thereby increases the incentives to invest into research and development ex ante (Hall, 2009). Lastly, some companies might have a comparative advantage in patent enforcement, i.e. the negotiation and collection of licensing fees as well as patent litigation (Galasso et al., 2011).

Apart from these positive effects, patent transactions might also have negative effects on innovation. Lemley and Shapiro (2006) argue that patent transactions constitute a serious threat of ex post hold-up for manufacturing firms, which discourages investment in research and development (R&D) and requires policy action. They find that PAEs file between 30 and 40 percent of all patent suits in the computing and electronics industries. Similarly, the risk of litigation, for instance in the form of preliminary injunctions, discourages companies' R&D efforts (Lanjouw and Schankerman, 2001). In addition, there might be an effect on the direction of technological change. For instance, Lerner (1995) finds that biotechnology firms avoid R&D in technology fields where the risk of litigation is high.

Given the negative effects that patent transactions might have on innovation, Merges (2009) considers corrective public policies including the (partial) ban of patent trades. The concern that patent trades might deter innovation is currently at the center of public policy debate and has been expressed in a recent report by the U.S. Federal Trade Commission on the intellectual property marketplace

(FTC, 2011). In addition, Section 34 of the Leahy-Smith America Invents Act (signed by President Obama on September 16, 2011) requires the Comptroller General of the Unites States to carry out a study of the consequences of patent litigation by PAEs.

The market for inventions can be segmented into those deals that involve the licensing of inventions and those deals that involve the sale of inventions.[3] Evaluating the relative size of these two segments is a challenging task due to limited data availability. According to evidence from Europe and Japan, about 10 percent of patents get licensed.[4] Using data on U.S. patents granted before 1983, Serrano (2010) finds that about 14 percent of patents are traded at least once over their life cycle.[5] The sale segment of the market is of particular interest when studying the role of PAEs. A patent gives its owner the right to produce using the underlying invention as well as the right to exclude others from using the protected invention. For PAEs the value of a patent stems from the right to exclude others. Their business model focuses on the collection of licensing fees and attaining damages awarded from litigation.

There are no academic studies that provide dollar estimates of the size of the market of traded patents. However, Oliver Wyman, a consultancy, estimates the markets size at $1.2 billion per year.[6] IPotential, a patent broker, provides an

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[3]See for example Anand and Khanna (2000) and Arora et al. (2004) for empirical work on the licensing segment of the market for inventions for the U.S., Gambardella et al. (2007) for Europe and Motohashi (2008) and Kani and Motohashi (2012) for Japan. Estimates for the market size of the licensing segment in the U.S. and also globally are reviewed by Arora and Gambardella (2010).

[4]Based on data from the PatVal EU survey, Gambardella et al. (2007) find that 11 percent of patents in Europe get licensed. Motohashi (2008) finds that 9 percent of Japanese patents get licensed.

[5]Chesbrough (2006) provides estimates for patents granted between 1985 and 1997 and finds that 25 percent of patents are traded at least once over their life cycle. However, these estimates are likely to be upward biased. For instance, the estimates include assignments (and releases) of patents as collateral to financial institutions.

[6]As reported by Kelley (2011). These estimates are based on fifty structured interviews of

estimate of about $1.5 billion for the year 2008 (Chernesky, 2009).

Using companies' filings with the U.S. Securities and Exchange Commission (SEC) and the United States Patent and Trademark Office's (USPTO) database on patent ownership, this paper introduces a newly constructed data set of 105 patent portfolios consisting of 1,510 U.S. granted patents and 535 patent applications traded among companies between 1990 and 2011. The combined observed market value of these 105 portfolios is $872,525,049 (in 2005 $).[7] The average market value of a traded patent in this data set is $426,663. Out of the 105 patent portfolios, 31 portfolios (or 29.5 percent) were acquired by PAEs. The companies' filings also reveal that a clear distinction between the licensing and selling of patents does not always exist. In 17 out of the 105 deals (or 16.2 percent), the contractual agreement between the two companies included additional royalty payments from the new to the previous owner of the traded patents. Furthermore, 48 agreements (or 45.6 percent) included a license back to the previous owner of the traded patent portfolio.

The benefit of providing direct market values of traded patent portfolios comes with the drawback that the reported trades are unlikely to represent a random sample of all patent trades. Combined with a random sample of 468 patent portfolios from the population of all traded patent portfolios and controlling for selection, the new data set allows for the derivation of estimates of the total market for patents. The total size of the market for patents is estimated at $9,975 million in 2005. The average value of a traded patent in this random sample of traded patents is $505,062. Patents belonging to the technology fields

inventors, intellectual property law firms, brokers and intermediaries, academics, industry experts, and intellectual property counsels from large technology companies carried out in early 2009.

[7] All U.S. dollar figures reported in the remainder of this chapter are in 2005 $.

'Electrical and Electronics' and 'Computers and Communication' account for 24.5 and 24.2 percent of the traded patents respectively, followed by 'Drugs and Medical' patents, which account for 14.1 percent. Trades involving PAEs account for an estimated $379,888,702 or 3.8 percent out of the total market of $9,975 million.

Out of the total population of all patents, only a small number of patents get litigated. Lanjouw and Schankerman (2001) find that 0.6 percent of patents get litigated over their lifetime. The litigation rate, which is defined as the number of cases per hundred patents, is 1.1 percent. The litigation rate is larger than the rate of patents litigated as the same patent might be litigated several times.[8] The litigation rate for patents from the random sample of 468 traded patent portfolios is 2.3 percent during the acquiring entity's term of ownership. However, patents acquired by PAEs do not have an increased likelihood of being litigated compared to other traded patents.

1.2 Data

1.2.1 Data set of 105 patent portfolios traded between 1990 and 2011

The two main data sources used to construct the data set of patent portfolios traded among companies between 1990 and 2011 are companies' SEC filings

[8]Lanjouw and Schankerman (2001) estimates are based on patents with application years 1980-1984. Lemley (2001) estimates that at most 2 percent of all patents are ever litigated based on the patent stock in force and the number of patent lawsuits in 1999.

Table 1.1: Key Word Search Results

Phrase	Number of documents containing the phrase	Number of identified patent portfolio trades
"patent purchase agreement"	1,028	54
"patent assignment agreement"	1,535	21
"patent rights purchase"	160	8
"patent sale agreement"	123	5
"purchase of patent rights"	710	3
"transfer of patent rights"	329	3
"patent acquisition agreement"	177	3
"patent transfer agreement"	229	2
"sale of patent rights"	198	2
"patent rights assignment"	133	1
"patent rights acquisition"	108	1
"patent purchase and assignment"	34	1
"patent sale and assignment"	15	1
"acquisition of patent rights"	721	0
"patent transfer and sale agreement"	99	0
"patent rights sale"	76	0
"patent rights transfer"	47	0
"patent transfer and assignment"	14	0
"patent purchase and transfer"	6	0
"patent sale and transfer agreement"	4	0
"patent acquisition and assignment"	0	0
"patent acquisition and transfer"	0	0
Total	5,746	105

Notes: Data are companies' SEC filings between 1990 and 2011 accessed through LexisNexis.

and patent assignment data from the USPTO.[9] Key word searches for phrases such as "patent purchase agreement" in the SEC filings were used to identify those documents that might contain information about traded patent portfolios. In total, 22 different phrases were used for the key word search and resulted in 5,746 documents (Table 1.1). The number of almost six thousand hits largely overstates the number of identified traded patent portfolios for two reasons: (i) a document might not contain information about a traded patent portfolio or (ii) the same patent trade is reported in multiple documents.[10] An example

[9]LexisNexis Academic provides access to the full text of EDGAR filings by domestic and foreign companies from 1991 as well as annual and quarterly reports and proxy statements of more than 4,000 US companies, filed with the SEC since 1987. EDGAR is the SEC's Electronic Data Gathering, Analysis and Retrieval system that provides access to those forms (including annual and quarterly reports) that companies are required to file with the SEC by law. The USPTO's patent assignment data is available at http://assignments.uspto.gov.

[10]One example for a search result that does not provide information on an actual patent trade comes from the key word search for the phrase "patent sale agreement", which returned the

of such multiple reporting of the same traded patent portfolio is Advance Cell Technology Inc.'s filing of Form 424B3 (prospectus; filed on June 27th, 2007) as well as Exhibit 10 (material contract; filed on March 28th, 2007). Both documents report the acquisition of patents formerly owned by Infigen Inc.

After reading the full text of the 5,746 documents, I identified 105 patent portfolios traded between January 1st, 1990 and June 30th, 2011.[11] An example is Cirrus Logic Inc.'s filing of Form 10-K (annual report; filed on May 25th, 2011) that resulted from the key word search for the phrase "patent purchase agreement":

> "On July 13, 2010, we entered into a Patent Purchase Agreement for the sale of certain Company owned patents. As a result of this agreement, on August 31, 2010, the Company received cash consideration of $4.0 million from the purchaser."

Companies file a variety of different forms with the SEC, but information about traded patent portfolios is mostly reported directly in the annual or quarterly reports, in current reports or in the exhibits to those reports (Table 1.2).[12] The SEC requires companies to report "Material Definitive Agreements" or "Mate-

10-K filing of Vitesse Semiconductor Corp. (filed on December 31st, 2008) containing the following statement: "The Company typically sells its products to its customers pursuant to the Company's standard sales agreement, which contains [...] certain provisions for indemnifying the customer against losses, liabilities, costs, and expenses resulting from a claim alleging that the Company's product infringes a third-party's United States *patent. The sales agreement* [emphasis added] generally limits the indemnification obligations in a variety of industry-standard respects, including, but not limited to [...]".

[11] The data includes all traded patent portfolios up until June 30th, 2011, which were reported in SEC filings by August 1st, 2011. The data is possibly truncated in the sense that there might be patent portfolios traded before June 30th, 2011, which are reported in SEC filings after August 1st, 2011.

[12] Companies have to file annual reports on form 10-K and quarterly reports on form 10-Q. If a company qualifies as a small business it uses forms 10-K-SB and 10-Q-SB. In addition companies must file the current report form 8-K to announce major events.

Table 1.2: Search Results by Type of SEC Form

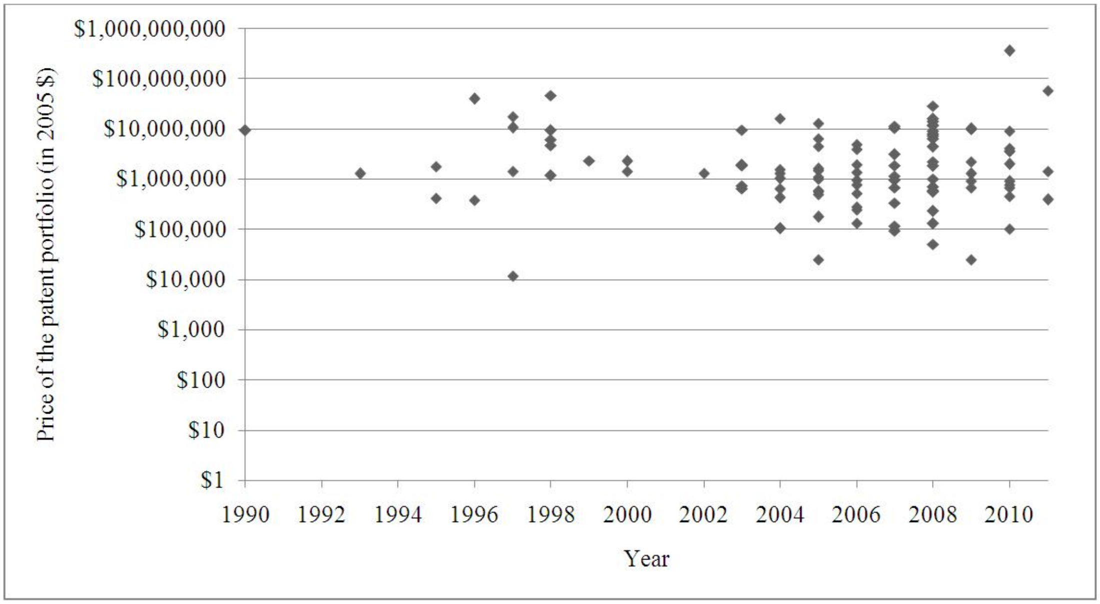
Form number	Form description	Number of identified patent portfolio trades
Exhibit 10	Material contracts	38
10-K(-SB), 10-Q(-SB)	Annual and quarterly reports (small business)	29
8-K	Current report	14
S-1	Registration statement	8
Exhibit 2	Plan of acquisition	6
Exhibit 99	Additional exhibits	6
Exhibit 4	Instruments defining the rights of security holders	1
Exhibit 16	Letter re change in certifying accountant	1
10SB12G	Registration of securities for small business	1
424B4	Prospectus	1
Total		105

Notes: Data are companies' SEC filings between 1990 and 2011 accessed through LexisNexis.

rial Contracts". These are defined as an agreement or contract "not made in the ordinary course of business which is material to the registrant" (Regulation S-K, Item 601 b 10 i). Item 601 b 10 ii further specifies that "[i]f the contract is such as ordinarily accompanies the kind of business conducted by the registrant and its subsidiaries, it will be deemed to have been made in the ordinary course of business and need not be filed unless it falls within one or more of the following categories, in which case it shall be filed except where immaterial in amount or significance: [. . .] B. Any contract upon which the registrant's business is substantially dependent, as in the case of continuing contracts to sell the major part of registrant's products or services or to purchase the major part of registrant's requirements of goods, services or raw materials or any franchise or license or other agreement to use a *patent* [emphasis added], formula, trade secret, process or trade name upon which registrant's business depends to a material extent; [. . .]."

As demonstrated by the examples of Advance Cell Technology Inc. and Cirrus Logic Inc. above, information about traded patent portfolios can come from the buyer or the seller of the patent portfolio. Out of the 105 traded patent port-

Figure 1.1: Price of traded Patent Portfolios by Year of Execution



Notes: Data on 105 traded patent portfolios from the SEC sample.

folios, 60 (or 57 percent) were reported through the seller and 45 (or 43 percent) through the buyer of the patent portfolio.

The number of deals per year increased over time (Figure 1.1). Only 16 deals occurred before 2000. The number of deals peaked in 2008, when 19 deals occurred. Data for 2011 is truncated, since the sample only includes deals up June 30th, 2011 reported by August, 1st, 2011.

The companies' SEC filings reveal information about the companies involved in the trade, the date of the trade, the price paid as well as other contractual agreements such as a license back to the seller or agreements about additional royalty payments.[13] In general, the filings do not include information about the individual patents that were traded.

[13]Patent portfolio prices are reported in nominal terms. To derive prices in real terms, I use GDP price index data provided by the Bureau of Economic Analysis (BEA) using 2005 as the base year (available at www.bea.gov).

The USPTO's assignment database provides information on the change of ownership of individual patents for all recorded patent assignments from August 1980 onwards. While there is no legal obligation for the buyer of a patent to request the recording in the change of ownership, section 261 of the U.S. patent act states that "[a]n assignment, grant, or conveyance shall be void as against any subsequent purchaser or mortgagee for a valuable consideration, without notice, unless it is recorded in the Patent and Trademark Office within three months from its date or prior to the date of such subsequent purchase or mortgage." A company buying a patent therefore has the strong incentive to request the recording of the ownership change. In addition, patent attorneys strongly recommend the recording (Dykeman and Kopko, 2004).

Given the information on the seller (i.e. assignor) and the buyer (i.e. assignee), the USPTO's assignment database provides a list of all the U.S. patents and patent applications that were traded between these companies. In addition to the names of the assignor and assignee, I used the information on the date of the trade to control for the possibility that the same seller and buyer trade patent portfolios multiple times. The SEC filings specify the date of the contractual agreement, while the USPTO's assignment database provides information on the execution date of the ownership change. An example of such a change in ownership if provided in Figure 1.2, which identifies the U.S. patents traded between Cirrus Logic Inc. (as the seller, i.e. assignor) and Huai Technologies LLC (as the buyer, i.e. assignee) in 2010.[14]

Additional information about the individual patents and patent applications traded in the portfolios, such as the application date, the grant date, the

[14] To save space, the list of patents is truncated in the figure. The complete assignment record includes information on 60 traded U.S. patents.

Figure 1.2: Example of an Assignment Record

Assignment: 50

Reel/Frame: 025039/0292 **Pages:** 24

Recorded: 09/26/2010

Conveyance: ASSIGNMENT OF ASSIGNORS INTEREST (SEE DOCUMENT FOR DETAILS).

Assignor

1 CIRRUS LOGIC, INC. **Exec Dt:** 08/24/2010

Assignee

1 HUAI TECHNOLOGIES, LLC
2711 CENTERVILLE ROAD, SUITE 400
WILMINGTON, DELAWARE 19808

Properties

Pat #	Pub #	App #	Pat #	Pub #	App #	Pat #	Pub #	App #
5473573	NONE	08239608	5455526	NONE	08288442	5452244	NONE	08288580
5506810	NONE	08291093	5442588	NONE	08291155	5473566	NONE	08304508
5500819	NONE	08315934	5701143	NONE	08381189	5592077	NONE	08387218
5567963	NONE	08410868	5529945	NONE	08410869	5530392	NONE	08420138
5581513	NONE	08423825	5732024	NONE	08424653	5663984	NONE	08434656
5535165	NONE	08497267	5598374	NONE	08502479	5537353	NONE	08521867
5612644	NONE	08521891	5568431	NONE	08531755	6025840	NONE	08534279
5654932	NONE	08538903	5585744	NONE	08543210	5687132	NONE	08548752
5583822	NONE	08551526	6108015	NONE	08552197	5570320	NONE	08554297
6041389	NONE	08559379	5761694	NONE	08565388	5636174	NONE	08584565
5848101	NONE	08591864	5701270	NONE	08595236	5600606	NONE	08612113

Notes: Data from the USPTO assignment database. To save space, the list of patents is truncated in the figure. The complete assignment record includes information on 60 traded U.S. patents.

patent class, and the number of citations received from later patents, was obtained from the USPTO Patent Full-Text database for granted patents (PatFT) and USPTO Patent Full-Text database for applications (AppFT).[15]

It is possible to categorize patents with respect to industries or technology fields based on the patent class of a granted patent or a patent application. The USPTO assigns one of over 400 patent classes as the primary subclass to every patent or patent application. Hall et al. (2001) provide a matching of these over 400 patent classes to 6 technology field categories. 1,050 out of 2,045 patents and patent applications (51 percent) in the sample are 'Computers and Communication" patents. 493 (or 24 percent) are 'Electrical and Electronics' patents and 283 (or 14 percent) are 'Drugs and Medical' patents (Table 1.3, Column 2 "SEC

[15]PatFT provides information on all granted U.S. patents since 1976 and is available at: http://patft.uspto.gov. AppFT provides information on all published U.S. patent applications since March 2001 and is available at: http://appft.uspto.gov.

Table 1.3: Comparison of the Distribution of Technology Fields

Technology field	Current samples: SEC sample (105 portfolios)	Current samples: Random sample (468 portfolios)	NBER: All granted patents 1994-2006
Chemicals (excl. Drugs)	5.28 %	10.63 %	13.96 %
Computers and Communication	51.34 %	24.22 %	21.90 %
Drugs and Medical	13.84 %	14.09 %	10.73 %
Electrical and Electronics	24.11 %	24.50 %	21.00 %
Mechanical	3.03 %	11.75 %	16.34 %
Other	2.40 %	11.75 %	16.08 %
Total number of patents	**2,045** (=100%)	**1,796**(=100%)	**1,867,475**(=100%)

Notes: Technology field definitions based on Hall, Jaffe and Trajtenberg (2001).

sample").[16]

To account for the heterogeneity in patent quality, I use the number of citations received from later patents and the number of claims as proxy variables. Although there exists only limited empirical evidence on the validity of citations by later patents as an indicator of patent quality, citations have emerged as the standard measure of patent quality.[17] To account for truncation in the observed citation history (i.e. I observe a longer citation history for patents granted earlier), I only consider citations received within 5 years after the grant date of a patent. Empirical analysis have also used the number of claims in the granted

[16] A more detailed breakdown of the technology fields based on 37 subcategories is provided in the appendix (Table A.1).

[17] There are some notable exceptions: Carpenter et al. (1981) compare citations for 100 "important" patents between 1969 and 1974 with 102 control patents that had been issued in the same year. In their study, important patents are defined as patents that they match with "the 100 most significant technical products" selected by the journal Industrial and Research Development in 1969 and 1970. These 100 patents were cited 494 times between 1968 and 1974, compared with 102 control patents that were issued in the same years and were cited only 208 times. Similarly, Albert et al. (1991) find a strong association between the number of citations counts and the technical importance of 77 silver halide technology patents granted between 1982 and 1983. Their measure of technical importance is based on the expert opinion of 20 researchers and research managers at Eastman Kodak, all of whom were working in the area of silver halide technology. Trajtenberg (1990) shows that citations counts are positively correlated with the estimated social surplus that 456 improvements in CAT scanners created over time. Moser et al. (2011) analyze patents protecting new hybrid corn varieties and find that citations are highly correlated with the magnitude of inventive output measured as the percentage increase in yield or income over existing varieties.

patent or patent application as a proxy for the quality or scope of a patent (Tong and Frame, 1994; Sakakibara and Branstetter, 2001), and claims have also been proposed as an additional, complementary measure to patent citations for the importance of patented inventions (Lanjouw and Schankerman, 2004).

The advantage of claims over citations lies in the availability of claims data on both granted patents as well as pending applications. Therefore, the current data set includes the information about the number of claims for all 2,045 patents and applications. The citation data is only available for the 1,510 patents that were granted at the time of sale plus an additional 227 patent applications that turned into granted patents at some point between the time of sale and the date of the data collection (August 1st, 2011). 308 out of the original 535 patent applications were still pending (as of August 1st, 2011).

The average patent in the sample receives 5.4 citations from later patents within 5 years after its grant date (Table 1.4). The average number of claims per patent is 23.08 (Table 1.4).

In addition to information on patents, the USPTO's assignment database provides information on assignments of trademarks. Only 6 out of the 105 deals included trademarks in addition to patents. The average number of trademarks per deal is 0.98 (Table 1.5).

Data on annual revenues were obtained for all public companies in the sample from the Compustat database. Since the sample is based on SEC filings, at least one of the two companies involved in each of the deals is a public company that discloses information on annual revenues.

In order to identify PAEs, I started with lists of previously identified PAEs.

Table 1.4: Summary Statistics: Unit of Observation is a granted U.S. Patent or Patent Application

	# of observations	Mean	Std. Dev.	Min	Max
SEC sample					
Quality of the patent					
Number of citations	1,737	5.4000	8.1959	0	81
Number of claims	2,045	23.0768	18.7465	1	217
Patent age at execution					
Technology fields					
Chemicals (excl. Drugs)	2,045	0.0528	0.2237	0	1
Computers and Communication	2,045	0.5134	0.4999	0	1
Drugs and Medical	2,045	0.1384	0.3454	0	1
Electrical and Electronics	2,045	0.2411	0.4278	0	1
Mechanical	2,045	0.0303	0.1715	0	1
Other	2,045	0.0240	0.1530	0	1
Foreign patent family members					
EU patent family member	2,045	0.5457	0.4980	0	1
JP patent family member	2,045	0.4279	0.4949	0	1
Random sample					
Quality of the application					
Number of citations	1,796	4.6553	7.1996	0	62
Number of claims	1,796	19.0384	14.9826	1	173
Patent age at execution	1,796	80.0262	53.3225	0	354
Technology fields					
Chemicals (excl. Drugs)	1,796	0.1463	0.3084	0	1
Computers and Communication	1,796	0.2422	0.4285	0	1
Drugs and Medical	1,796	0.1409	0.3480	0	1
Electrical and Electronics	1,796	0.2450	0.4302	0	1
Mechanical	1,796	0.1175	0.3221	0	1
Other	1,796	0.1481	0.3553	0	1
Foreign patent family members					
EU patent family member	1,796	0.4822	0.4998	0	1
JP patent family member	1,796	0.4076	0.4915	0	1

Notes: Number of citations is the number of citations received from subsequent U.S. patents within 5 years after the grant date. Average patent age at execution is measured as the number of months between the application date and the execution date. Technology field definitions based on Hall et al. (2001).

Fischer and Henkel (2009) identify 48 different PAEs. Bessen et al. (2011) provide a list of 14 publicly traded PAEs. The combined list consists of 59 PAEs. However, PAEs do not necessarily acquire patents under their company's name, but use shell companies instead. One example is Intellectual Ventures, one of the dominant players in the industry. A list of shell companies that Intellectual Ventures uses is provided in Niro (2007). Starting with this initial list combining the findings of Bessen et al. (2011), Fischer and Henkel (2009) and Niro (2007),

Table 1.5: Summary Statistics: Unit of Observation is a traded Patent Portfolio, SEC Sample

	Mean	Std. Dev.	Min	Max
Ln(price)	14.2879	1.7640	9.3781	19.7026
Quality of the portfolio				
Ln(1 + number of citations)	3.2157	1.9139	0	6.7226
Ln(1 + number of claims)	4.9818	1.6325	0	8.3481
Average patent age at execution	84.6871	40.5151	8	200.5
Type of company				
Patent Assertion Entity	0.2952	0.4583	0	1
Trademarks				
Number of trademarks	0.9810	6.2680	0	53
Technology fields				
Chemicals (excl. Drugs)	0.0908	0.2397	0	1
Computers and Communication	0.5053	0.4724	0	1
Drugs and Medical	0.2118	0.3871	0	1
Electrical and Electronics	0.0663	0.1945	0	1
Mechanical	0.0771	0.2225	0	1
Other	0.0486	0.1767	0	1
Foreign patent family members				
EU patent family member	0.5741	0.4036	0	1
JP patent family member	0.4369	0.4054	0	1
Participation				
Reporting relevance	6.6385	29.6202	0.0014	291

Notes: Number of citations is the number of citations received from subsequent U.S. patents within 5 years after the grant date. *Average patent age at execution* is measured as the number of months between the application date and the execution date. Technology field definitions based on Hall et al. (2001).

I was able to identify additional shell companies through a matching of addresses. Several shell companies used identical addresses (up to the office suite number) in their filings with the USPTO.

Out of the 105 patent portfolios, 31 (or 30 percent) are acquired by PAEs (Table 1.5). On the individual patent level, 587 out of the 2,045 granted patents and patent applications (29 percent) are acquired by PAEs (Table 1.10). However, the deal value of all patent portfolios acquired by PAEs only accounts for 13 percent of the trade value of all trades combined ($114,123,340 out of $872,525,049; Table 1.10).

Information on foreign patent family members for the traded U.S. granted patents or patent applications were obtained from the European Patent Office (EPO) espacenet database and the EPO Patent register.[18]

1.2.2 Random sample of 468 traded patent portfolios

In order to identify the population of all traded patents, I use all records on patent assignments from the USPTO's assignment database.[19] The database contains 3,045,258 records for the time period 1980 to 2010. Each record lists a reason for the conveyance of a patent. The recordation form that companies have to file with the USPTO (Form PTO-1595) provides a checkbox for "Assignment", "Security Agreement", "Change of Name" and "Others", which allows companies to list their own reason. As a result, the database contains over 9,000 reasons for conveyance. 2,848,200 records (or 93.5 percent) list "Assignment of Assignors Interest" as the reason for conveyance. The next two most common reasons for conveyance are "Change of Name" (41,892 records; 1.4 percent) and "Corrective Assignment" (23,609 records; 0.8 percent). In a first step, all records that did not list "Assignment of Assignors Interest" as the conveyance reason were excluded. For the remainder of the paper, I will refer to these remaining 2,848,200 records as the assignment records.

These assignment records include the initial assignment from the inventor to his or her employer. Since these initial assignments take place within the boundaries of a company, they should not be considered as part of the market

[18] The EPO espacenet database is available at http://worldwide.espacenet.com/. The EPO Patent Register is available at https://register.epo.org/espacenet/regviewer.

[19] Google and the USPTO have entered into an agreement to make the USPTO's assignment data available to the public at no cost. Bulk data can be downloaded at http://www.google.com/googlebooks/uspto.html.

for patents. In order to account for the initial assignments, the first assignment record for each patent with an execution date between the application date and the grant date is dropped. This leads to a total of 824,391 records for the period 1990 to 2010. For the remainder of the paper, I will refer to these records as the *re-assignment* records.

The number of re-assignments increased significantly from 17,011 in 1990 to 60,869 in 2004 (Figure 1.3, by year of execution). The date of recording a re-assignment is not necessarily the same as the execution date of a re-assignment. Re-assignment data is therefore truncated, which needs to be taken into account in particular when interpreting data for the most recent years. In addition, the analysis only includes those patents and patent applications that were granted by December 31st, 2010. Two of the reasons to select the year 2005 as the base year for most of the analysis in the paper were to minimize these effects of truncation.

The number of re-assigned patents in 2005 is 53,807. However, this number overstates the number of traded patents. Companies might choose to re-assign patents within the boundaries of the company. In addition, the re-assignment records might include initial assignments (those from the inventor to his or her employer) if the assignment took place after the grant date. I use the name standardization routines provided by the NBER Patent Data Project to identify the type of assignor.[20] All re-assignments that list an individual as the assignor (as identified by the name standardization routine) are dropped. This reduces the number of re-assigned patents to 42,712. However, due to the large number of spelling variations it is not possible to identify internal transfers of patents

[20]Stata do files for the name standardization routines are available at https://sites.google.com/site/patentdataproject (accessed on 12/05/2011).

Figure 1.3: Number of Re-Assignment Records by Year of Execution

Notes: The USPTO Assignment database contains 3,045,258 records for the time period 1980 to 2010. 2,848,200 records (93.5 percent) list "Assignment of Assignors Interest" as the reason for conveyance. The next two most common reasons for conveyance are "Change of Name" (41,892 records; 1.4 percent) and "Corrective Assignment" (23,609 records; 0.8 percent). There are over 9,000 reasons for conveyance. The figure only shows the "Assignment of Assignors Interest". The date of recording a re-assignment is not necessarily the same as the execution date of a re-assignment. For all re-assignments with the conveyance reason "Assignment of Assignors Interest" recorded in 2008 (233,722 records), the execution date is on average 170 days before the recording date. The data is therefore truncated, which needs to be taken into account in particular when interpreting the most recent years in the above figure. Data on assignments from the USPTO.

automatically. Instead, a manual analysis is required (see below).

The re-assignment records (one for each granted patent or patent application) can be grouped into portfolios of patents based on the name of the assignee, the name of the assignor and the execution date of the deal. This groups the 42,712 patents into 8,797 portfolios. Since several steps of the analysis cannot be automated (such as the identification of internal transfer), I took a random sample of 800 patent portfolios out of the population of 8,797 portfolios.

A manual analysis of the assignee and assignor of these 800 patent portfolios shows that 223 portfolios are re-assigned internally. In addition, 109 patent portfolios list an individual as the assignee, but were missed by the name standardization routine. Excluding both of these portfolio types generates the random sample of 468 patent portfolios containing 1,796 U.S. patents and patent applications traded in 2005. At the time of trade in 2005, 1,430 patents out of the 1,796 patents (80 percent) were already granted and the remaining 366 were granted between the time of trade and December 31st, 2010.

Based on the 6 technology field definitions used above, 440 out of 1,796 patents and patent applications (24.5 percent) in the random sample are 'Electrical and Electronics' patents. 435 (24.2 percent) are 'Computers and Communication' patents and 253 (14.1 percent) are 'Drugs and Medical' patents (Table 1.3).[21] While a concentration of trades within a few industries is also observed in the empirical literature on technology licensing, their composition differs. In their analysis of the structure of licensing contracts, Anand and Khanna (2000) find that almost 80 percent of licensing deals occur in either 'Chemicals' (including drugs; 46 percent), 'Electronic and Electrical Equipment' (22 percent) and 'Industrial Machinery and Equipment' (12 percent).

In order to identify, whether certain technology fields are over- or underrepresented in the current sample, one has to control for the distribution of patents across technology fields in the total population of patents. The NBER patent database contains information on the technology field of all U.S. utility patents granted between 1976 and 2006 (Hall et al., 2001).[22] The USPTO granted

[21] A more detailed breakdown of the technology fields based on 37 subcategories is provided in the appendix (Table A.2).

[22] An update containing all granted patents until 2006 is available at: http://elsa.berkeley.edu/~bhhall/patents.html (accessed on 12/05/2011).

Table 1.6: Comparison of the Number of Claims per Patent by Technology Field

Technology field	Current samples SEC sample (105 portfolios)	Random sample (468 portfolios)	NBER All grated patents 1994-2006
Chemicals (excl. Drugs)	17.53	16.66	15.82
Computers and Communication	25.59	22.91	19.16
Drugs and Medical	28.39	17.72	18.04
Electrical and Electronics	17.05	18.94	16.40
Mechanical	19.71	18.29	14.75
Other	15.59	16.43	15.12
Average	**23.08**	**19.04**	**16.63**

Notes: Technology field definitions based on Hall et al. (2001).

1,867,475 patents between 1994 and 2006. Comparing the distribution of these patents across technology fields with the SEC sample of 2,045 traded patents, the random sample of 1,796 traded patents and the NBER data shows that there exist significant differences between the three. Compared to the NBER data, patents from the random sample in the fields 'Computers and Communication', 'Drugs and Medical' and 'Electrical and Electronics' are overrepresented, while 'Chemicals (excl. Drugs)', 'Mechanical' and 'Others' patents are underrepresented (Table 1.3, columns (3) and (4)).

In order to identify differences between the patents in the random sample and 'the average patent', I compare the number of claims in the random sample with the number of claims per patent in the NBER patent data. The number of claims per patent is significantly higher in the random sample (Table 1.6). This difference in the number of claims, which cannot be explained with the difference in the distribution across technology fields, points to a higher quality of the average patent in the random sample compared to the average patent in the total population.

The average patent in the random sample receives 4.66 citations from later

Table 1.7: Summary Statistics: Unit of Observation is a traded Patent Portfolio, Random Sample

	Mean	Std. Dev.	Min	Max
Quality of the portfolio				
Ln(1 + number of citations)	1.3858	1.4644	0	6.4425
Ln(1 + number of claims)	3.3340	1.2335	0	7.9980
Average patent age at execution	66.8601	47.0763	0	354
Type of company				
Patent Assertion Entity	0.0299	0.1705	0	1
Trademarks				
Number of trademarks	1.2799	6.1370	0	74
Technology fields				
Chemicals (excl. Drugs)	0.1400	0.3291	0	1
Computers and Communication	0.2085	0.3892	0	1
Drugs and Medical	0.1690	0.6570	0	1
Electrical and Electronics	0.1203	0.2946	0	1
Mechanical	0.1469	0.3233	0	1
Other	0.2153	0.3893	0	1
Foreign patent family members				
EU patent family member	0.5477	0.4644	0	1
JP patent family member	0.3940	0.4562	0	1
Participation				
Reporting relevance	0.0926	0.7729	0	12.3720

Notes: *Number of citations* is the number of citations received from subsequent U.S. patents within 5 years after the grant date. *Average patent age at execution* is measured as the number of months between the application date and the execution date. Technology field definitions based on Hall et al. (2001).

patents within 5 years after its grant date (Table 1.4). In comparison, the average patent in the NBER patent data receives 3.0 citations within the first 5 years after the patent grant (Hall et al., 2001).[23] The average patent in the random sample received a larger amount of citations compared to the average patent in the total population, implying a higher quality of the patents in the sample.

In addition to patents, 73 out of the 468 deals (16 percent) included trademarks. The average number of trademarks per deal is 1.28 (Table 1.7).

[23]Hall, Jaffe and Trajtenberg (2001) provide a description of the initial NBER patent data set. An update containing all patents and citations until 2006 was drawn from http://elsa.berkeley.edu/~bhhall/patents.html. Calculations are based on the updated data set.

Data on annual revenues were obtained for all public companies in the sample from the Compustat database. For 107 out of 468 traded patent portfolios, at least one of the two companies involved in the deal is a public company that discloses information on annual revenues. For the remaining 361 traded patent portfolios, neither the buying nor the selling company disclosed information on annual revenues.

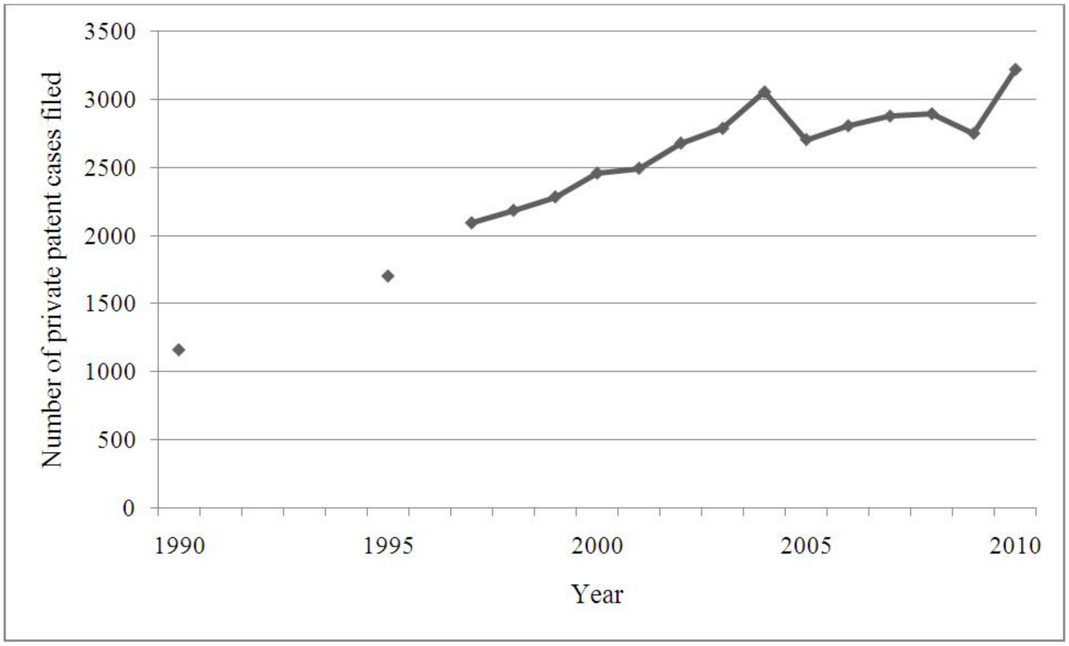
1.2.3 Litigation data

Aggregate data on patent litigation is available from the Statistics Division of the U.S. Courts. The number of private patent cases per year increased from 1,165 in 1990 to 3,055 in 2004 and has remained around 3,000 since 2004 (Figure 1.4).[24] Litigation data on individual patents is available from the IP Litigation Clearinghouse (IPLC) database.[25] This database contains information on patent litigation from 2000 onwards. A manual search of the database for each of the 1,796 patents in the random sample was carried out covering the time period between the time of the deal in 2005 and November 1st, 2011. If a patent was sold and re-assigned once more at some point after 2005, only the time period between the initial trade in 2005 and the second trade was considered.

[24] Data on private patent cases from the Judicial Facts and Figures 2005, 2009 and Judicial Business of The U.S. Courts 1997, 1998, 1999, 2010 available at www.uscourts.gov/Statistics.aspx (accessed on 09/27/2011). Data is available for the years 1990, 1995 and annually from 1997 onwards.

[25] Access to the IPLC database was provided by Lex Machina, Inc.

Figure 1.4: Number of private Patent Cases filed (1990-2010)



Notes: Data from Judicial Facts and Figures 2005, 2009 and Judicial Business of The U.S. Courts 1997, 1998, 1999, 2010.

1.3 Results

1.3.1 Estimates of the market value of a traded patent and the size of the market for patents

As a first (and potentially biased) estimate, I use the total market value of traded patent portfolios divided by the number of granted patents and patent applications from the SEC sample as an estimate of the market value of traded patents. The average patent has a value of $426,663 (Table 1.8, column 2). Since prices are only observed at the portfolio level, it is not possible to obtain the full distribution of individual patent values. However, a lower bound for the maximum patent market value and an upper bound for the minimum patent market

Table 1.8: Market Value of traded Patents and Patent Applications

	SEC sample	Random sample (estimates)
Number of traded portfolios	105	468
Sum of traded portfolios	$ 872,525,049	$ 907,092,108
Number of granted patents and patent applications	2,045	1,796
Max patent value (lower bound)	$ 40,040,039	$ 12,032,107
Mean patent value	$ 426,663	$ 505,062
Min patent value (upper bound)	$ 1,075	$ 4,162

Notes: In 2005 $.

value can still be obtained from the average patent value per portfolio.[26] The lower bound for the maximum patent market value (based on the SEC sample) is \$40,040,039 and the upper bound for the minimum value is \$1,075 (Table 1.8, column 2).

As mentioned above, the patent portfolio deals reported to the SEC might not represent a random sample of all traded patents. In order to control for selection and to derive estimates of the value of traded patents for the random sample, I combine the SEC sample of 105 patent portfolios with the random sample of 468 patent portfolios from the population of all traded portfolios and estimate a Heckman selection model.

The main specification of the regression analysis is given by the following equation:

$$\begin{aligned} ln\,(Price_j) \;&=\; \alpha + \beta_1 ln\,(1+\textstyle\sum_i Citations_{ij}) + \beta_2 ln\,(1+\textstyle\sum_i Claims_{ij}) \\ &\quad +\beta_3 Average\ patent\ age_j + \beta_4 EU_j + \beta_5 JP_j + \beta_6 PAE_j \\ &\quad +\beta_7 Trademarks_j + \gamma Technology\ Field_j + \epsilon_j \end{aligned}$$

where $ln\,(Price_j)$ is the natural logarithm of the real price of the traded

[26] The maximum over the average patent value per portfolio is a lower bound for the maximum patent market value. Similarly, the minimum over the average patent value per portfolio is an upper bound for the minimum patent market value.

patent portfolio j, $Citations_{ij}$ counts the number of later patents that cite patent i belonging to patent portfolio j, $Claims_{ij}$ counts the number of claims of patent i belonging to patent portfolio j, $Average\ patent\ age_j$ is measured as the average number of months between the application date and the execution date of the patent transaction, EU_j is the share of patents in the portfolio that have a European patent application patent family member, JP_j is the share of patents in the portfolio that have a Japanese patent application patent family member, PAE_j is a dummy variable equal to one if the buyer of the patent portfolio j is a patent assertion entity, $Trademarks_j$ is the number of trademarks traded in addition to the patents and $Technology\ Field_j$ refers to the 5 technology fields ("Computers and Communication" is the excluded category).

Table 1.9, column 1, gives the OLS estimates without controlling for possible selection bias. A 10 percent increase in the number of citations leads to a 4.4 percent increase in the value of the traded portfolio (significant at the 1 percent level). The sign of the coefficient of the number of claims is negative, but not significant. The sign of the coefficient of the average patent age at the date of execution is positive, but also not significant. The signs of the coefficients of the share of European and Japanese patent family members are both positive as expected, but also not significant. The coefficient on the dummy variable that controls for the buyer of the portfolio being a PAE is negative, but not significant. The coefficient of the number of trademarks is positive, but also not significant. The technology field 'Computers and Communication' is the omitted category. The coefficient of the technology field 'Mechanical' dummy variable is positive and significant at the 5 percent level. The coefficient of the technology field 'Other' dummy variable is negative and significant at the 1 percent level. The R^2 is equal to 0.32.

Table 1.9: Regression Results, Unit of Observation is a traded Patent Portfolio, dependent Variable is $ln\,(Price)$

	(1) *OLS*	(2) *Heckman-Selection*	(3) *Heckman-Outcome*
Ln(1 + number of citations)	0.4356 ***	0.0131	0.4446 ***
	(0.1453)	(0.0750)	(0.1366)
Ln(1 + number of claims)	-0.0000	0.2534 ***	0.1562
	(0.1629)	(0.0866)	(0.1871)
Average patent age at execution	0.009	0.0040 **	0.0018
	(0.0042)	(0.0018)	(0.0040)
EU patent family member	0.1460	-0.0040	0.1134
	(0.5367)	(0.2448)	(0.5032)
JP patent family member	0.7833	0.3799	0.8404
	(0.5654)	(0.2420)	(0.5299)
Patent assertion entity	-0.5713	1.1676 ***	-0.2198
	(0.3734)	(0.2637)	(0.4456)
Number of trademarks	0.041	-0.0071	0.0396
	(0.0261)	(0.0137)	(0.0246)
Chemicals (excl. Drugs)	-0.4382	-0.4170	-0.5156
	(0.7176)	(0.2908)	(0.6700)
Drugs and Medical	-0.1287	-0.2812	-0.0483
	(0.5701)	(0.2504)	(0.5352)
Electrical and Electronics	-0.2999	-1.4750 ***	-0.6338
	(0.8434)	(0.4441)	(0.8308)
Mechanical	1.5800 **	-0.2645	1.4929 **
	(0.7740)	(0.2892)	(0.7188)
Other technology field	-2.7944 ***	-0.8435 ***	-3.0952 ***
	(1.0079)	(0.3083)	(0.9508)
Reporting relevance		0.2444 ***	
		(0.0526)	
Constant	12.6233 ***	-2.3324 ***	11.1442 ***
	(0.7772)	(0.3410)	(1.2540)
Lambda			0.6008
			(0.4133)
Rho			0.3997
sigma			1.5030
N	105	573	105
R^2	0.3160		
adj. R^2	0.2268		
PseudoR^2		0.3930	

Standard errors in parentheses, $^{*}p< 0.1$, $^{**}p< 0.05$, $^{***}p< 0.01$

Notes: The omitted technology field is "Computers and Communication". Technology field definitions based on Hall et al. (2001). Number of citations is the number of citations received from subsequent U.S. patents within 5 years after the grant date. Average patent age at execution is measured as the number of months between the application date and the execution date.

In order to control for selection bias, I estimate a Heckman selection model. The outcome equation is the same as the one specified above. The selection equation includes the same independent variables as the outcome equation with the variable *Reporting relevance* added. For each company in the sample *Reporting relevance* captures whether the company is a public company and how relevant the traded patent portfolio is compared to the size of the company.

$$Reporting\ relevance_k = d_k \frac{Number\ of\ traded\ patents_j}{Annual\ revenue_k}$$

where d_k is a dummy variable equal to one if company k is a public company and the second term gives the ratio of the number of patents traded in portfolio j to the size of company k as measured by the annual revenue (in millions) of company k in the year of the execution of the patent portfolio transaction. For each deal j, I observe the reporting relevance for the buyer (company k) as well as the seller (company l) of the patent portfolio. In order to aggregate this information to the level of the unit of observation (i.e. the patent portfolio deals), I define the reporting relevance for portfolio j as:

$$Reporting\ relevance_j = max\left\{Reporting\ relevance_k, Reporting\ relevance_l\right\}.$$

Table 1.9, column 2 gives the estimates of the selection equation of the Heckman model. The coefficients on the number of claims and the average patent age are positive and significant at the 1 percent and 5 percent level, respectively. The coefficient of the dummy variable controlling for the buyer of the portfolio being a PAE is positive and significant at the 1 percent level. Compared to the baseline technology field ('Computers and Communication'), portfolios with a larger share of 'Electrical and Electronics' and 'Other' patents are less likely to be reported, both significant at the 1 percent level.

The coefficient of the participation variable (i.e. *Reporting relevance*) is positive and significant at the 1 percent level. The estimates for the outcome equation of the Heckman model are reported in table 1.9, column 3. A 10 percent increase in the number of citations leads to a 4.4 percent increase in the value of the traded portfolio (significant at the 1 percent level). With the exception of the coefficient of the number of claims, none of the coefficients change their sign compared to the OLS estimates and are similar in their magnitude.

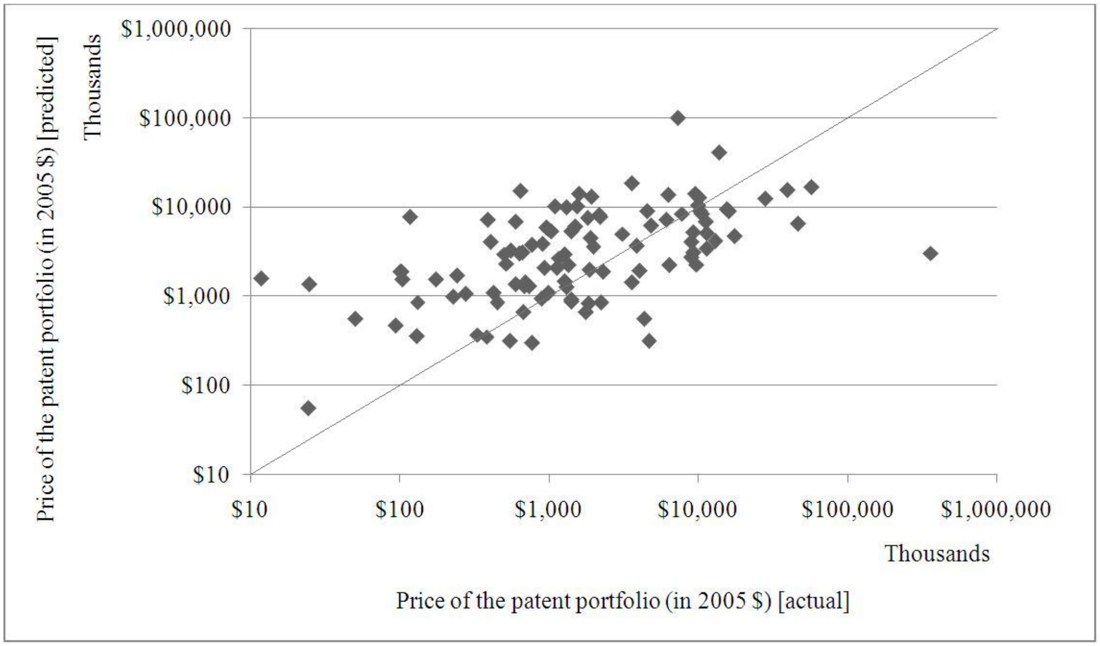
The estimates of the coefficients of the outcome equation are used to derive the predicted market values for the patent portfolios of the random sample. Figure 1.5 plots the actual values of the price for each portfolio of the SEC sample versus the predicted value of the portfolio price.

The estimated mean value of a traded patent portfolio from the random sample is $1,938,231. The estimated mean patent value for a patent in the random sample is $505,062 (Table 1.8, column 3).

To the best of my knowledge, there is no open access or subscription based database on traded patent portfolios providing information on the value of the portfolio or individual patents. While not offering access to the actual database, ThinkFire, a patent brokerage firm, provides summary statistics on the 309 traded patent portfolios that compose the ThinkFire transaction database (2008 edition).[27] The mean value of a traded patent family for patents traded between 2002 and 2008 is $383,000 (in nominal terms). Unfortunately, no additional information about the types of companies involved or the patent portfolios is provided and therefore it is not possible to condition on any of the characteristics

[27] Zaretzki (2009), Executive Vice President at ThinkFire, presented information about the ThinkFire transaction database at the Berkeley Center for Law and Technology conference on Theory and Practice of Patent Valuation in February 2009. Slides are available at www.law.berkeley.edu/files/zaretzki.pdf (accessed on 12/05/2011).

Figure 1.5: Actual versus predicted Price of the Patent Portfolio



Notes: Data on 105 traded patent portfolios from the SEC sample.

in my data set to carry out a more advanced comparison between the market value estimates in the two different data sets.

Out of the total estimated value of $907,092,108 of patent portfolios in the random sample, portfolios worth an estimated $34,547,114 (or 3.8 percent) are acquired by PAEs (Table 1.10). Similarly to the SEC sample, the share of the number of patents acquired by PAEs is larger than the share of the estimated value of patents acquired by PAEs.

In order to provide estimates of the total market in 2005, the previous estimates need to be scaled up from the size of the random sample of (initially) 800 observations to the size of the total market of 8,797 traded patent portfolios. The total market in 2005 is estimated at $9,975 million. Portfolios worth an estimated $379,888,702 are acquired by PAEs.

Table 1.10: Significance of Patent Assertion Entities

	Number of portfolios	Number of patents	Value
SEC sample			
Total	105	2,045	$872,525,049
Patent Assertion Entities	32	587	$114,123,340
in percent	*30.48%*	*28.70%*	*13.08%*
Random sample			
Total	468	1,796	$907,092,108
Patent Assertion Entities	14	155	$34,547,114
in percent	*2.99%*	*8.63%*	*3.81%*

Notes: Technology field definitions based on Hall et al. (2001).

Previous research on the role of PAEs allows for a plausibility check of the estimated market value of portfolios acquired by PAEs. Bessen et al. (2011) provide estimates for the investment of 14 public PAEs in acquiring patents for the time period 2000 to 2010. Given the total amount of $1.7 billion for the entire time period, the average annual investment is about $155 million (about 41 percent of my estimate of about $380 million). In comparing my estimates with those of Bessen et al. (2011), one has to keep in mind that public PAEs are only a subset of all PAEs.

1.3.2 Litigation of traded patents

Out of the 1,796 traded patents of the random sample, 27 are litigated during the acquiring entity's term of ownership. Since some of these patents are appearing in more than one case, the total number of cases is larger at a total of 42 cases. The litigation rate is 2.3 percent during the acquiring entity's term of ownership. Patents acquired by PAEs do not have an increased likelihood of being litigated compared to other traded patents. Out of the 42 cases, only 3 cases involve a PAE. The litigation rate for PAEs is 1.9 percent. However, given the small number of observations, the results have to be interpreted with care.

1.4 Conclusions

The chapter introduces a new data set of 105 patent portfolios consisting of 2,045 U.S. granted patents and patent applications traded among companies between 1990 and 2011 including information on the market value of these portfolios. This data set is combined with a random sample of 468 patent portfolios consisting of 1,796 U.S. granted patents and patent applications from the population of all patent portfolios traded in 2005.

Contrary to the "conventional wisdom" that traded patents are of low value, I find that the average patent traded in one of the portfolios from the random sample has a market value of $505,062. The total size of the market for patents is estimated at $9,975 million in 2005 and is significantly larger compared to previous estimates. While significant in market size, the sale segment of the market for technology is much smaller than the licensing segment.

Patents belonging to the technology fields 'Computers and Communication' and 'Electrical and Electronics' each account for over 24 percent of the traded patents, followed by 'Drugs and Medical' patents, which account for about 14 percent.

Patent portfolios acquired by PAEs account for about $380 million or 3.8 percent out of the total market. This points out the relatively small impact that PAEs have on facilitating markets for technology and also highlights the limited importance that PAEs have in the market for patents. Any evaluation of public policy considering the ban of patent trades in order to prevent litigation by PAEs must consider the negative impact with respect to the efficient allocation of new technologies of also banning the vast majority of trades that do not include PAEs.

Traded patents are more likely to be litigated than non-traded patents. The litigation rate for traded patents is 2.3 percent during the acquiring entity's term of ownership. However, patents acquired by PAEs do not have an increased likelihood of being litigated compared to other traded patents.

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CHAPTER 2

PATENTS, CITATIONS, AND INVENTIVE OUTPUT: EVIDENCE FROM HYBRID CORN

2.1 Introduction[1]

A common concern with patent data is that "inventions that are patented differ greatly in 'quality,' in the magnitude of inventive output associated with them" (Griliches, 1990, p. 1669). For example, Simon Kuznets (1962, p. 37) observes that "the main difficulty with patent statistics is, of course, the enormous range in the magnitude of the inventions covered." Counts of citations received from subsequently granted patents are the most commonly used measure to control for the magnitude of patented inventions, but there is little systematic evidence on the relationship between citations and the size of inventions. We use field trial data for patented new corn hybrids to examine whether counts of citations by later patents are a meaningful proxy for the size of innovative output. Specifically, we match patented improvements in hybrid corn with field trial data for new hybrids to measure the size of improvements in crop yields and revenues.

Corn is one of the world's leading food crops, and has accounted for up to a quarter of harvested acreage in the United States throughout much of the 20th century. U.S. breeders began to hybridize corn seeds after 1908, when plant scientists George H. Shull and Edward M. East crossbred two inbred (homozygous) plants, and found that the first filial (F1) generation plant generated more corn than open-pollinated varieties.[2] Shull and East's inbreds, however, were

[1]This chapter is based on joint research with Professors Petra Moser and Paul W. Rhode.

[2]Homozygous inbred plants carry the same alleles (forms) of a gene; they are simultaneously

stunted and did not produce enough seeds to make their discovery commercially viable. In 1917, Donald F. Jones created the first double cross (F2) hybrids by crossing two F1 lines; Jones' F2 hybrid out-performed open-pollinated varieties and produced enough seeds to be commercially viable. In 1923, Henry A. Wallace, who later founded the Pioneer Seed Company, introduced Copper Cross, as one of the first commercial hybrid seeds.[3] In 1933, hybrid seed was planted on less than one percent of U.S. corn acreage. By 1939, its share had risen to almost half. By 1960, nearly all U.S. corn acreage was hybrid seed (Griliches, 1957, 1960; Olmstead and Rhode, 2008, pp. 64-67). Advances in yields, which are the focus of this analysis, determined the onset and speed of adoption (Griliches, 1957).[4]

Improvements in hybrid corn became subject to utility patents after 1980, when the U.S. Supreme Court ruled in favor of Ananda M. Chakrabarty, a microbiologist at General Electric. Chakrabarty had developed the genetically-engineered pseudomonas bacterium to break down crude oil into substances that could serve as food for aquatic life, and was denied a patent by the USPTO. In 1980, the Supreme Court decided that the pseudomonas bacterium should be patentable because the "relevant distinction is not between living and inanimate things" but between naturally existing and human-made substances (Diamond

female and male, and can therefore pollinate themselves and create identical offspring. When two homozygous inbreds are crossed, all of the offspring share the same combination of alleles.

[3]Other early breeders include the Funk Brothers Seed Co. of Bloomington, Illinois, who had marketed hybrid corn seeds in 1916 and the Connecticut Agricultural Experiment Station, which had sold hybrid corn in 1921 (Funk Bros. Seed Co., 1940; Fitzgerald, 1990). In the 1960s and 1970s, improvements in inbred plants and methods of cultivation increased yields from F1 plants sufficiently to allow breeders to market F1 instead of F2 lines (Kloppenburg, 2004, Sutch, 2008). Today F1 seeds account for nearly all corn seed planted in the United States.

[4]Griliches (1957) examines cross-sectional differences in the use of hybrid seed corn and explains differences in the lag with which seed producers adopt hybrid corn based on market density and marketing costs. Griliches (1960) documents that adoption followed an S-shaped growth curve across regions: the rate of adoption was slow at first, accelerated to a peak at approximately mid-point, and then decelerated.

vs. Chakrabarty, 447 U.S. 303 (1980)). In 1985, the USPTO de facto extended utility patents to sexually propagated plants, such as hybrid corn (Ex parte Hibberd, 227 USPQ 443 Bd. Pat. App. & Int).[5] This unilateral decision by the USPTO was affirmed by the U.S. Supreme Court in 2001, when the Court decided that the same seed could be protected simultaneously by a utility patent and a plant variety protection certificate, an alternative type of intellectual property rights (IPRs), which the Plant Variety Protection Act had created in 1970 to provide IPRs for seeds (J.E.M. Ag Supply vs. Pioneer Hi-Bred International, 534 U.S. 124).[6]

[5]Ex parte Hibberd established that corn plants are patentable under regulation 35 U.S.C. 101, which states that "[w]hoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefore, subject to the conditions and requirements of this title." Regulation 35 U.S.C. 112 specifies the requirements for reporting: the "specification shall contain a written description of the invention, and of the manner and process of making and using it, in such full, clear, concise, and exact terms as to enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the same, and shall set forth the best mode contemplated by the inventor of carrying out his invention."

[6]On December 24, 1970, Congress passed the Plant Variety Protection (PVP) Act, which authorized the US Department of Agriculture to issue PVP certificates, which provide exclusive marketing rights for new varieties of sexually propagated plants (seeds) that are "uniform, stable, and distinct from all other varieties." In contrast to utility patents, PVP certificates are narrower, covering only one variety, and they include no claims. PVP certificates also do not allow breeders to prevent competitors from using a new variety in their breeding program. Fungi, bacteria, and first-generation (F1) hybrids were initially excluded from PVP protection (Strachan, 2004). Distinctness requires that the variety differs by one or more identifiable morphological, physiological, or other characteristics (which may include processing or product characteristics, such as, milling and baking characteristics in the case of wheat); uniformity implies that any variations are describable, predictable and commercially acceptable; and stability in the sense that the variety, when sexually reproduced or reconstituted, will remain unchanged with regard to its essential and distinctive characteristics with a reasonable degree of reliability (7 U.S.C. Sec. 2401 cited in U.S. Court of Appeals, Fifth Circuit, Delta Pine vs. Peoples' Gin 694 F.2d 1012 Jan. 3, 1983). A 1994 Amendment to the PVP Act extended PV protection to F1 seeds. Varieties that have been sold or used in the United States for more than 1 year or abroad for more than 4 years are also ineligible. PVP certificates remain in effect for 18 years from the date of issue. Breeders are required to submit 2,500 sample seeds (with germination rates of at least 85) when the application is filed, these sample seeds are stored at the National Seed Storage Laboratory in Ft. Collins, CO (Strachan, 2004). In 1992, protection required a filing fee of $250 and an examination fee of $1,900, as well as the deposit of 2,500 viable seeds (Strachan, 2004). "The 'importance' or 'value' of characteristics to the productivity of the crop are not considered when making novelty decisions. Therefore, 'cosmetic' traits, those which do not contribute to the productivity of the crop, can be used to distinguish among varieties. Some breeders argue that basing judgments on cosmetic traits trivializes a PVP certificate" (Strachan, 2004). Breeders do not appear to use

The USPTO granted the first utility patent for a corn hybrid on August 26, 1986. Until 2005, all patents for hybrid corn reported field trial data on yields in bushels per acre and moisture levels.[7] Yields are the bottom-line measure for improvements. Data on yields in combination with data on moisture levels allow farmers to calculate the expected revenue from new hybrids: Moisture levels above 15 percent decrease the value of corn by increasing drying costs and the risk of spoilage.[8]

The reported field trial data for 256 patented corn hybrids indicate that most patented corn hybrids produced less corn than comparable hybrids that were already in production: 58 percent of patented hybrids between 1986 and 2005 produce less corn than the highest-yielding comparison hybrids; 56 percent generate less income. 23 percent of patented hybrids produce less corn than the average comparison hybrid. On average, patented hybrids yield one percent less corn and one percent less income than the highest-yielding existing hybrids.

Field trial data also indicate that the size of improvements in yields and income decline over time. More than 70 percent of hybrids patented after 1998 produce less corn than existing varieties, compared with 47 percent before 1998, and more than 63 percent produce less income after 1998, compared with 53 before 1998.[9] On average, hybrids that were patented between 1998 and 2005

PVPs to protect first or second generation hybrid corn: By November 2008, Pioneer had applied for 549 PVP certificates, but all of them cover inbred lines rather than hybrids.

[7] One firm changed their reporting practices on their patent applications, affecting patents granted from 2005 onwards. See below for further details.

[8] See Uhrig and Maier (1992) for a detailed discussion of the effects of moisture. Other characteristics influence the quality of hybrid corn seeds primarily through their effects on yields: time to maturity, resistance to pest and diseases, drought-tolerance, and adaptability to soil quality. Field trials control for such characteristics by growing comparable crops under identical conditions. In addition to yields and moisture, we also collect data on variation in the relative maturity of hybrid corn. The naming practices used by Pioneer for its hybrid corn seeds reveal the relative maturity levels (www.pioneer.com/home/site/ca/products/product-naming-system, accessed on 12/05/2011).

[9] A total of 134 hybrids were patented up to 1998 and 122 hybrids between 1999 and 2005.

yield two percent less corn and two percent less income than existing hybrids.

Controlling for alternative factors, including variation in the number of days that hybrids need to mature, or in disease resistance, cannot explain these results. Most importantly, corn hybrids vary according to the climatic conditions that they require to thrive, and in particular in the number of days with adequate growing conditions that they require to mature (e.g. Griliches, 1957, 1960; Hicks and Thomison, 2004, pp. 482-484 and 493-495).[10] As a first cut, we collected information on variation in the relative maturity of Pioneer hybrids between 1997 and 2005, when the company encoded information on relative maturity in the names of new seeds. These data indicate no systematic changes in relative maturity over time. The average hybrid corn plant in our data has a relative maturity index of 5.03 before 1998, 5.31 after 1998 and 5.19 across the sample on a scale from 0 to 9 (ranging from 'very full' to 'very short' relative maturity), with no discernible decrease in maturity over time.[11]

[10]Guidelines for selecting hybrid corn recommend that farmers first "select hybrids with maturity ratings appropriate for your geographic area or circumstances" to allow corn to reach physiological maturity before the first frost that kills it. Then, "Step 2, Choose hybrids with consistently high yields across a number of locations and/or over years [...] Choosing a hybrid because it possesses a particular trait, such as big ears, many kernel rows, deep kernels, or upright leaves will not ensure high yields; instead, look for stability in performance across environments." ("Steps for Selecting Hybrid Corn", Ohio State Extension, Publication AGF 125-95, http://ohioline.osu.edu/agf-fact/0125.html, accessed 06/16/2011).

[11]Another omitted characteristic of corn hybrids relates to the sugar content of corn, which increases the value of harvested corn per weight. We focus on field corn (as opposed to garden variety sweet corn or popcorn), which accounts for more than 98 percent of acreage and nearly all research activity of large commercial breeders. However, the sugar content also became an important issue for field corn after 2005 when the Renewable Fuel Program of the Energy Policy Act mandated renewable fuel use in gasoline, which is typically corn-based, to reach 7.5 billion gallons by calendar year 2012 (nearly double compared with 2005 levels; Westcott, 2007). In 2005/06 ethanol accounted for 14 percent of U.S. production in field corn, compared with 55 percent for animal feed (Westcott, 2007). Corn-based ethanol production had increased gradually from 1.6 billion gallons in 2000/01 to 3.5 billion gallons in 2005/06, but was expected to increase to nearly 8 billion gallons by 2015/16. As a result, the share of ethanol in corn use was projected to increase drastically, and without being anticipated by the USDA and breeders, after 2006 to 31 percent by 2016/17 (Westcott, 2007), leading to an increase in the price of corn, and more than likely also shifting R&D efforts towards crops with high sugar-content. Hybrids in our data, which include patent grants only until 2005, were not affected by this policy change.

These results suggest that plant breeders may use utility patents for strategic reasons, to protect themselves from litigation or to extract licensing revenues. In the hybrid corn sector, rapid increases in patenting coincide with a period of consolidation when Monsanto acquired nearly all plant breeders in the industry except Pioneer. In February 1996, Monsanto formed a joint venture with DeKalb Genetics, acquiring a 40 percent stake in the producer of hybrid corn seed (New York Times, Feb. 2, 1996, p. D4). In late September 1996, Monsanto began the process of acquiring Asgrow, its partner in developing Roundup-Ready soybeans, and a seed company with a long history in developing vegetables, and most recently soybeans (New York Times, Sept. 25, 1996, p. D3, Fernandez-Cornejo, 2004, pp. 31, 34).[12] The transaction was completed by 1998 and they soon began to market Roundup-ready hybrid corn, which could withstand the application of Monsanto's powerful Roundup (glyphosate) herbicide to destroy weeds. In January 1997, Monsanto agreed to purchase Holden's Foundation Seeds for one billion dollars (Charles, 2001, p. 197; New York Times, Jan. 7, 1997, p. D8).[13] On May 11, 1998, Monsanto announced that it would pay $2.3

[12] Asgrow was amenable to a partnership with Monsanto, because its researchers had created squash that was engineered to resist a virus, and required a fragment of DNA, the 35S promoter that Monsanto researchers had isolated and patented in the 1980s; Monsanto paid $240 million for Asgrow's corn and soybean business, and Asgrow acquired the rights to use the 35S promoter (Charles, 2001, p. 195). "Monsanto's acquisition of Agrow, and its restrictive contracts with many other smaller seed companies, forced people to radically revise their estimates of what germplasm was worth. It appeared that elite germ plasm was just as rare and difficult to create from scratch as new and valuable genes. Seed companies never had earned substantial profits. But it suddenly became clear to many in the industry that they had become very valuable indeed. Control over seed companies meant access to billion-dollar markets." (Charles, 2001, p. 197)

[13] Charles (2001, pp. 198-199) describes the importance of Holden's Seed Foundation: "Until the 1960s the nation's mom-and-pop seed companies had relied on breeding programs at agricultural universities, which regularly distributed, free of charge, new corn hybrids. But those publicly funded breeding programs gradually fell behind the efforts of Pioneer and DeKalb and closed down. Ron Holden stepped into the gap. Holden's maintained a small but well-run breeding program that delivered new 'inbred' lines that became the parents of hybrid seed sold by family-owned seed distributors all over the country. The smaller companies often relied exclusively on Holden's for their seed stock; larger enterprises such as Golden Harvest or Dobelers or even DeKalb used parental lines from Holden's to supplement their own breeding programs.

billion for the remainder of DeKalb; the transaction was completed on December 1, 1998 (New York Times, May 12, 1998, p. D2; Dec. 1, 1998, p. C4). In 1997, Monsanto introduced the DeKalb's YieldGard hybrid corn, which is resistant to the European corn borer.

After 1997, only two major players remained in the industry, Monsanto and Pioneer, which had resisted Monsanto's attempts of purchasing it. In August 1997, Du Pont acquired a 20 percent stake in Pioneer; in October 1999, Du Pont purchased the remaining 80 percent (Fernandez-Cornejo, 2004, p. 33).

In 1999, Pioneer held 42 percent of the seed market, compared with Monsanto's share of 12 percent (Figure B.1). In 2003, Pioneer introduced its first bio-engineered hybrid; Herculex, which was resistant to the European corn borer. By mid-2004, however, Monsanto had pushed ahead of Pioneer as a market leader (Fernandez-Cornejo, 2004), possibly fueled by "surging crop prices, which allowed farmers to buy the latest bug-resistant, herbicide-tolerant corn" (Associated Press, August 25, 2010).[14]

If breeders patent for strategic reasons, and many patents do not improve on prior art, measures for the quality of patented inventions become particularly important (e.g., Griliches, 1990, p. 1669). With the availability of electronic data sets like the NBER patent citations data (Hall et al., 2001), counts of citations by later patents have emerged as the standard measure of patent quality.[15] There is however, to date no quantitative evidence to prove that citations are

Only Pioneer refused to use any material from Holden's. When one added it all up, corn lines from Holden's were the immediate ancestors for 40 percent of all the corn grown in the United States."

[14]In 2010, DuPont devoted half of its $1.4 billion research budget to agriculture, compared with Monsanto's $1.1 billion budget (Associated Press, August 25, 2010).

[15]An update containing all granted patents until 2006 is available at: http://elsa.berkeley.edu/~bhhall/patents.html (accessed on 12/05/2011).

positively correlated with the magnitude of improvements, which typically cannot be measured. Instead, existing studies compare citations counts with other measures of the "importance" of patents. Most prominently, Trajtenberg (1990) showed that citations counts are positively correlated with the estimated social surplus that 456 improvements in CAT scanners created over time.

Carpenter et al. (1981) compare citations for 100 "important" patents between 1969 and 1974 with 102 control patents that had been issued in the same year. In their study, important patents are defined as patents that they matched with "the 100 most significant technical products" selected by the journal Industrial and Research Development in 1969 and 1970. These 100 patents were cited 494 times between 1968 and 1974, compared with 102 control patents that were cited only 208 times, implying that an "important" patent received 4.94 citations on average compared to 2.04 citations for the average patent from the control group.

Similarly, Albert et al. (1991) find a strong association between the number of citations counts and the technical importance of 77 silver halide technology patents granted between 1982 and 1983. Their measure of technical importance is based on the expert opinion of 20 researchers and research managers at Eastman Kodak, all of whom were working in the area of silver halide technology.

Citations are also positively correlated with changes in the stock market valuations of firms that own the cited patents (Hall et al., 2005).

Field trial data for hybrid corn establish a positive and statistically significant relationship between counts of citations and the magnitude of improvements in patented plants. For example, OLS and negative binomial regressions imply that a 10 percentage point increase in yields is associated with 1.9 additional citations; a 10 percentage point increase in income is associated with 2.5 additional citations when the comparison is made with respect to the highest-yielding comparison hybrid. A 10 percentage point increase in yields is associated with 2.4 additional citations when the comparison is made with respect to the average comparison hybrid. Results are robust to controlling for the age of patents, time- and firm-fixed effects, linear and quadratic time trends.

Each patent document includes a number of claims that define the scope of the patent. Empirical analysis have used the number of claims as a proxy for the breadth of patents (e.g., Sakakibara and Branstetter, 2001), and claims have been proposed as an additional, complementary measure for the importance of patented inventions (Lanjouw and Schankerman, 2004). The number of claims per utility patent of hybrid corn increases over time even though the size of improvements becomes smaller, as breeders add claims to their own, firm-specific templates of patent applications.

We also compare citations with renewal data as an alternative measure of patent quality.[16] Schankerman and Pakes (1986) use renewal data for U.K., French, and German patents between 1950 and 1979 to estimate the value of patented inventions. Renewal data for U.S. patents between 1985 and 1991 indicates that renewals and citations are highly correlated (Bessen, 2008). Among 256 corn hybrids in our sample, 98 percent were renewed after four years. Similarly, nearly all patents for which we observe the renewal decision after eight and eleven years were also renewed, suggesting that renewal decisions are

[16] In addition, data on prize-winning innovations (Moser, 2012) have been proposed as measures for the quality of patents. To the best of our knowledge, no comparable data can be collected for corn hybrids. All-American Seed Selection Prizes are awarded to garden varieties for sweet corn, but no reliable data exist on prize-winning in field corn.

made independent of the size of the improvement of the protected corn hybrid.

We also test whether breeders strategically choose field trials that maximize the magnitude of their improvements. To measure this, we link two patented hybrids that are not directly compared to one another through at least one other comparison hybrid that is included in both patent applications. A total of 172 patented hybrids can be paired with existing hybrids. These indirect comparisons are subject to more measurement error than field trials that are directly reported on patent documents and were conducted under identical growing conditions, but results are suggestive. In indirect comparisons, only 35 percent of patented hybrids produce more corn and 35 percent generate more income than existing hybrids.

2.2 Utility patents for corn hybrids

Our data consist of 256 utility patents for hybrid corn granted between August 26, 1986 and March 8, 2005. All of these patents include field trial data, including information on yields and moisture of the new corn hybrid in comparison to already established corn hybrids. In 2002, Pioneer, one of the two large firms in the industry, stopped reporting moisture levels as a share of total weight on its patent applications. Since this information is needed to calculate the income per acre of a corn hybrid, we restrict our data to all hybrid corn patents with an application date up to September 9, 2002 (which corresponds to the granting dates August 26, 1986 to March 8, 2005). This window of analysis precedes the Energy Policy Act of July 29, 2005 (Pub.L. 109-58), which mandated an increase in the amount of bio-fuel in U.S. gasoline. Since ethanol is typically produced from corn, the Act increased the price of corn, and raised the value of corn with extremely high sugar content; this change in relative prices may have changed the direction of innovation.

For patents granted up to 2005, we can observe citations for a minimum of five years, which is how long it takes for annual counts of citations in the NBER patent data set to reach their highest level (Hall et al., 2001). Application dates for patent grants between August 26, 1986 and March 8, 2005 range from February 21, 1985 to September 9, 2002. The average patent grant occurs 28 months after the application, with a median of 24 months and a standard deviation of 15 months. We use application dates to measure the timing of invention.

Between August 26, 1986 and March 8, 2005, the United States Patent and Trademark Office granted a total of 1,181 utility patents in the subclass 800/320.1 *maize*. We focus on field corn (as opposed to garden variety sweet corn or popcorn), which accounts for more than 98 percent of acreage and nearly all research activity of large commercial breeders.[17] A total of 256 patents in this subclass cover inventions in hybrid field corn; 118 of these patents cover both a hybrid and at least one parent inbred plant. For example, USPTO 6,864,409, assigned to DeKalb, states "inbred wddq1 has been used to prepare an F1 hybrid corn plant, designated dk642," and compares dk642 with established hybrids.[18] An additional 488 patents cover inbred corn lines only. Other patents assigned to the subclass *maize* include genetic modifications, such as the "terminator gene" for "Methods for maintaining sterility in plants" (USPTO 5,717,129).

[17] In 2007, U.S. farmers harvested 93,527,000 acres of field corn, compared with 622,946 acres of sweet corn, and 201,623 acres of popcorn (USDA, NASS, 2007 Census of Agriculture, Tables 33 and 34, available at www.agcensus.usda.gov/Publications/2007/Full_Report/index.asp; assessed on 12/03/2011).

[18] The hybrid dk642 is included in the data; it yields 6.55 percent more corn than the established hybrid dk636. USPTO 6,864,409 includes 29 claims and covers 10 additional hybrids; hybrid dk636 is covered by 2 additional patents and cited by 4 later patents.

A total of 245 patents for corn hybrids (96 percent) list subclass *maize* as their primary subclass. The remaining 11 patents list subclass *maize* as a secondary subclass.[19] In comparison, 68 percent of the 488 patents for inbred corn lines list subclass 800/320.1 as their primary subclass compared with only 14 percent of 437 patents for 'other' inventions.

In addition to claims, the number of hybrids that are covered by the same patent, as well as the number of other patents that cover the same hybrid can be used as measures for the scope or breadth of patents; our regressions include these measures as alternative controls and use a single patent as the unit of observation.

There does not exist a one-to-one match between a single patent and a single hybrid. A single patent can protect one or multiple hybrids. The average patent in our data covers 1.25 hybrids, but a small number of patents cover up to 10 hybrids.[20] Similarly, a single hybrid can be covered by multiple patents.[21] The average hybrid is covered by 1.2 patents (Table 2.1) and there is one case in which one hybrid is covered by 3 patents.[22]

[19]Out of these 11 patents, 7 patents list subclass 800/271 *Method of using a plant or plant part in a breeding process which includes a step of sexual hybridization - Method of breeding using gametophyte* as the primary subclass and there is one patent each that lists subclass 800/263 *Method of using a plant or plant part in a breeding process which includes a step of sexual hybridization - Breeding for altered carbohydrate composition*, subclass 800/267 *Method of using a plant or plant part in a breeding process which includes a step of sexual hybridization - Molecular marker is used*, subclass 800/274 *Via a male sterility genetic trait*, and subclass 800/275 *Method of using a plant or plant part in a breeding process which includes a step of sexual hybridization - Method of breeding maize* as the primary subclass.

[20]There exists significant variation between firms. While Pioneer patents always only cover one hybrid, DeKalb patents cover between 1 and 10 hybrids with an average of 1.37 hybrids per patent.

[21]An example of a hybrid that is covered by more than one patent is given by DeKalb's hybrid dk714, which is protected by the USPTO patents 6,359,200 and 6,380,467.

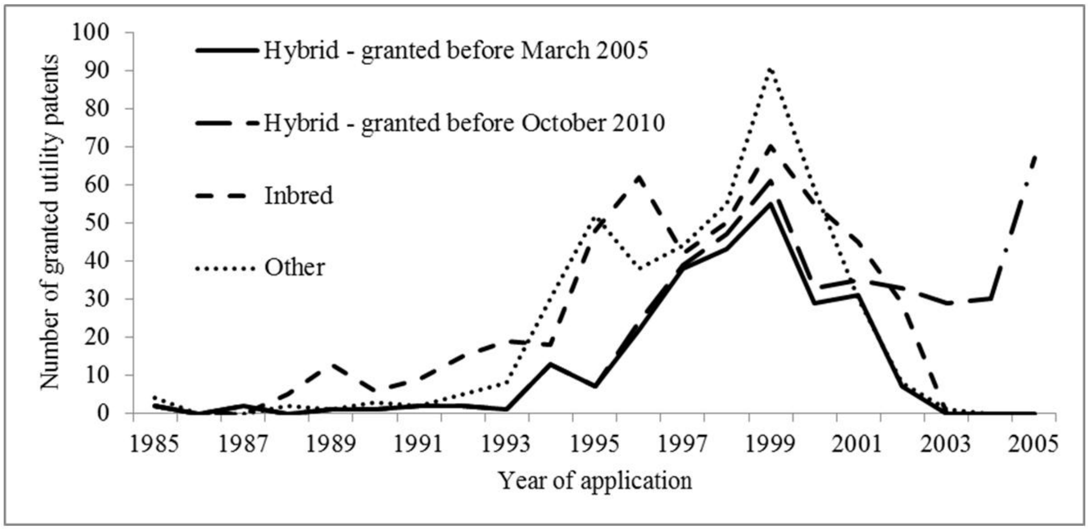
[22]The average Pioneer hybrid is protected by 1.02 patents, while the average DeKalb hybrid is covered by 1.35 patents.

Table 2.1: Summary Statistics

	Full sample				Excluding outliers			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Number of citations per patent	7.55	39.50	0	551	3.02	4.48	0	32
% increase in yield per acre (comparison with the highest-yielding hybrid)								
All comparisons	-1.06	5.22	-26.99	10.48	-1.14	5.22	-26.99	10.48
Direct comparisons	1.07	4.38	-16.86	12.34	1.04	4.38	-16.86	12.34
Indirect comparisons	-1.92	5.63	-26.99	9.99	-1.95	5.63	-26.99	9.99
% increase in yield per acre (comparison with the average-yielding hybrid)								
All comparisons	2.93	4.36	-11.96	16.94	2.88	4.31	-11.96	16.94
Direct comparisons	3.65	4.04	-8.40	16.94	3.62	4.00	-8.40	16.94
Indirect comparisons	1.06	5.25	-18.28	15.88	1.03	5.25	-18.28	15.88
% increase in income per acre (comparison with the highest-yielding hybrid)								
All comparisons	-0.96	5.05	-25.60	11.17	-1.03	5.05	-25.60	11.17
Direct comparisons	1.00	4.16	-16.01	11.31	0.97	4.17	-16.01	11.31
Indirect comparisons	-1.79	5.36	-25.60	11.45	-1.81	5.36	-25.60	11.45
# of claims	24.22	13.41	2	55	24.52	13.30	2	55
Year of application	12.93	2.71	0	17	13.11	2.27	4	17
# of hybrids covered by this patent	1.25	1.16	1	10	1.25	1.17	1	10
# of other patents covering this hybrid	0.20	0.51	0	2	0.21	0.51	0	2
Pioneer	0.50	0.50	0	1	0.51	0.50	0	1
DeKalb	0.43	0.50	0	1	0.43	0.50	0	1
Other firm	0.07	0.25	0	1	0.07	0.25	0	1

Notes: Five outliers have exceptionally high citation counts (136,137, 139, 212, and 551). Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 Maize available at www.uspto.gov. Data on income per acre incorporate information on the moisture content of a new hybrid in addition to its yield. Calculations use $2.25 per bushel of corn and drying costs of $0.04 per percent moisture above 15%. Price data from the United States Department of Agriculture's National Agricultural Statistics Service, available at www.nass.usda.gov. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. Year of application uses 1985 as the base year. The average patent covers 1.25 hybrids, but a small number of patents cover up to 10 hybrids; the variable # of hybrids covered by the patent includes for such variation. Similarly, the average hybrid is covered by 1.2 patents, but one hybrid is covered by 3 patents; the variable # of other patents covering this hybrid, controls for such variation.

Figure 2.1: Utility Patents in Subclass 800/320.1 *Maize* by Year of Application



Notes: Data include all 1,181 patents that were granted in subclass 800/320.1 Maize (available at www.uspto.gov) between January 1, 1985 and March 8, 2005. 256 patents are granted for hybrid corn. Some breeders stop to record comparable data for hybrid corn after March 8, 2005. For corn hybrids, the figure also shows all patents granted up to October 31, 2010 (when the data was collected).

2.2.1 Applications for utility patents protecting hybrid corn

Between 1985 and 1993, only a handful of breeders applied for utility patents for hybrid corn each year (Figure 2.1, utility patents for corn, granted by March 2005, measured at the date of application). In 1994, the number of hybrid corn patents increased rapidly to 13 patents, including seven applications by Pioneer, five by DeKalb, and one by Sandoz. In 1995, the number of patent applications dipped to seven (all assigned to Pioneer). After 1995, the number of patent applications increased smoothly to reach 55 in 1999. After 1999, patent applications for corn hybrids declined to 29 in 2000, and 31 in 2001. The low number of patent applications in 2002 is due to truncation (as explained above, only patents granted by 2005 are included in our data). Expanding the data to include patents granted by October 2010 increases the number of applications to

33 (instead of seven) in 2002, 29 (instead of zero) in 2003, 30 (instead of zero) in 2004, and 67 (instead of zero) in 2005.

Time trends in patenting for inbreds and other inventions closely mirror time trends in patenting for hybrid corn, with slightly larger numbers of applications for inbred corn lines and other inventions in hybrid corn in all years. Patents for inbred corn lines reach 13 for the first time in 1989, when Pioneer applied for 12 patents and Holden's Foundations Seeds applied for one patent. After a brief dip to six application in 1990, application for inbred corn lines increase to 19 in 1993 and 18 in 1994.

Interestingly, the onset of increasing numbers of patent applications for inbreds and other inventions precedes the onset of increasing numbers for corn hybrids, by two years, reaching a first peak of 52 patents for other inventions in 1995 and 62 patents for inbred patents in 1996. After a brief dip in 1996 and 1997 respectively, patents for inbred corn and other inventions reach another local peak with 70 and 91 patents respectively in 1999, and decline afterward.

2.2.2 Breeders' rationale to patent corn hybrids

The delayed onset of patenting is consistent with archival evidence on internal deliberations within the American Seed Trade Association (ASTA), which reveal that breeders of hybrid corn initially opposed the creation of formal property rights for sexually-propagated plants. In debates leading up to the Plant Variety Protection (PVP) Act of 1970, breeders of hybrid corn argued that patents would not benefit invention (Kloppenburg, 2004). Intuitively, breeders of hybrids may be less dependent on formal protection ex ante because the desirable characteristics of a hybrid do not appear reliably in offspring, and typically cannot be replicated without access to the parent (inbred) lines.[23]

Data on plant variety protection (PVP) certificates confirm that corn breeders also delayed adopting this alternative type of property right until the early 1980s, while breeders of soybeans began to apply for PVP certificates as early as 1971; in the 1990s, counts of PVP certificates per year converged for the two crops (Dhar and Foltz, 2007).

If secrecy provides an effective alternative, why did breeders of corn hybrids begin to use patents? One potential explanation is that the effectiveness of informal protection declined as breeding programs became more systematic and some breeders began to patent inbreds that they had developed based on their rivals' hybrids.[24] For example, one of the first patent grants to DeKalb (USPTO 4,594,810 granted June 17, 1986) covers a new inbred corn line, which DeKalb had developed by crossing two unpatented hybrid lines of Pioneer. Another patent grant to DeKalb in the same year covers the hybrid dk672 (USPTO 4,607,453; granted August 26, 1986), which DeKalb developed by crossing its own inbred HBA1 with B73Ht, an inbred "developed by Iowa State [...] available to the public." In 1995, DeKalb was granted another patent for a cross between its own inbred MBUB and B73 HT, "a public line available through Iowa State University" (USPTO 5,444,177; granted August 22, 1995). In 1999, DeKalb's

[23]This is consistent with historical evidence on an increase in the share of chemical innovations that firms chose to patent in response to an exogenous decrease in the effectiveness of secrecy. Analysis of exhibition data indicate that the large majority of 19th century inventions (more than 80 percent) were not patented and that patenting rates varied strongly across industries. Patenting rates for chemical innovations increased after scientific advances lowered the effectiveness of secrecy, both over time and relative to other industries (Moser, 2012). For contemporary firms, survey data indicate that firms in most industries, except for pharmaceuticals, prefer secrecy to patenting (e.g. Cohen et al., 2000).

[24]Taba et al. (2004, p. 104), however, state "It is extremely difficult to extract an inbred line once it has been hybridized."

inbred 3000200 (USPTO 5,969,212; granted October 19, 1999) incorporated material from Pioneer hybrid 3475 and Holden Foundation Seeds, LH 132; DeKalb's inbred 5014422 (USPTO 5,994,631; granted November 30, 1999) included Pioneer's hybrid 3293 as one parent.[25]

Breeders appear to incorporate both patented and unpatented varieties of rivals in the new lines that they develop. For example, DeKalb's inbred 01CSI6 (USPTO 5,777,196; granted July 7, 1998) is a descendent of the Pioneer hybrid 3779; DeKalb's inbred 2003929 (USPTO 5,856,614; granted January 5, 1999) is a descendent of the Pioneer hybrids 3615 and 3790 (USPTO 4,731,499; granted March 15, 1988).

2.2.3 Enforcement of patents for hybrid corn

Data on patent infringement cases from 2000 to present shows that none of the patents for hybrid corn in our data were part of patent litigation.[26] However, this is not to say that breeders do not enforce their patent rights. Monsanto states that as of October 10th, 2008, it has gone to trial over seed patents (not limited to hybrid corn) eight times, filed 128 law suits and settled about 700 times out-of-court.[27]

[25]In comparison, most conventional (non-GMO) hybrids include genetic material from a small number of open-pollinated varieties such as Reid.

[26]LexMachina provides access to every electronically available patent infringement case and docket event from 2000 to the present. Out of 256 patents for hybrid corn only one patent is mentioned in the documents available through the LexMachina database. By mistake, the defendant Mercedes-Benz of USA, LLC refers to patent USPTO 6,452,076 ("Inbred corn plant 7180 and seeds thereof") instead of USPTO 6,542,076 ("Control, monitoring and/or security apparatus and method") in their "answer and counterclaim" in case no. 8:10-CV-01909 DOC.

[27]See company website: www.monsanto.com/newsviews/Pages/Settling-the-Matter-Part-5.aspx (accessed on 12/02/2011). As of April, 2010, the number of lawsuits filed increased to 144 and the number of cases that have gone through full trial increased to 9 (www.monsanto.com/newsviews/Pages/why-does-monsanto-sue-farmers-who-save-seeds.aspx, accessed on 12/02/2011). However, Monsanto's website does not report up-

2.3 Field trial data on improvements in yields, moisture, and other characteristics

Since 1985, breeders of hybrid corn have adopted the practice of including information from field trials, including yields and moisture levels, in their patent applicants. Breeders report these comparisons voluntarily to establish the novelty of their plants, and they are able to choose the comparison plants. The USPTO does not check information in patent applications but misrepresentations would immediately invalidate a patent and breeders can count on competitors to conduct competing trials to verify their reports (Interview with Patent Examiner Gary Benzion, October 26, 2009). We will show below that changes in yields over time match changes in average yields in the United States, but also report evidence to suggest that breeders choose comparison plants strategically to increase the size of their improvements.

Field trials compare the performance of pairs of hybrids under identical growing conditions and in the same location. Field trials are carried out in a variety of locations. On the patent document, locations are typically listed as "all the hybrids' adapted growing areas" (USPTO 5,502,272 for Pioneer hybrid 3563) or "locations around the United States" (USPTO 5,449,855 for DeKalb hybrid dk743). Among the 256 patents in our sample, only 2 include explicit data on locations. Field trials for Pioneer's USPTO 4,731,499 (Pioneer hybrid 3790) were conducted in 8 test station across 6 U.S. states and one Canadian province: Bowling Green, Ohio; Woodstock, Ontario, Canada; Willmar, Minnesota; Huron, South Dakota; Janesville, Wisconsin; Alma, Michigan; Mankato, Minnesota; and North Platte, Nebraska. Tests for Pioneer's USPTO 4,737,596

dated information about the number of conflicts settled out-of-court.

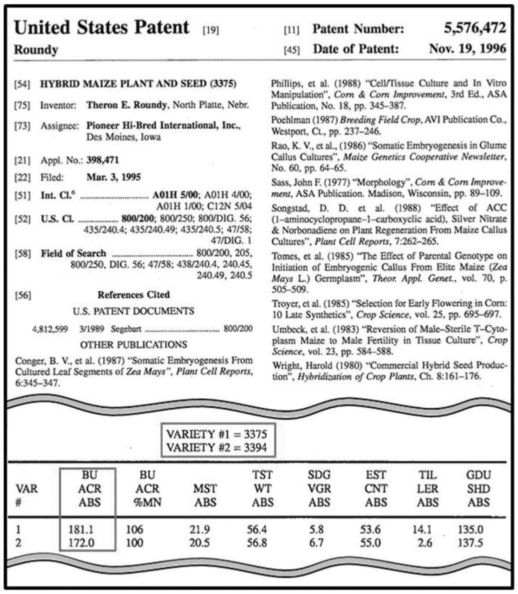
(Pioneer hybrid 3471) were conducted in 13 tests stations across 9 states: Johnston, Iowa; Princeton, Illinois; Algona, Iowa; Bowling Green, Ohio; Carrollton, Missouri; Garden City, Kansa; Huron, South Dakota; Marion, Iowa; New Holland, Pennsylvania; North Platte, Nebraska; Shelbyville, Illinois; Windfall, Indiana; and York, Nebraska. An additional four patents report only the number of locations for their field trials, without revealing locations: USPTO 6,506,964; 6,506,965; and 6,512,167 – all assigned to Rustica Prograin Genetique – report that performance data are based on "multilocation analysis of 15 locations." USPTO 6,646,188, assigned to Euralis, reports "multi-location analysis in 19 locations".

Yields are reported as bushels harvested per acre planted, normalized to a moisture level of 15.5 percent. Moisture levels are reported as the share of weight at harvest that is water. Corn at harvest has a high moisture level, especially following rain or an early frost. Corn with high moisture levels at harvest is costly to dry or rots in storage, and as a result sells at a discount beyond the actual share of corn that is water. To reduce moisture, farmers use fans and heaters to dry the corn. Corn has to be dried in a slow process at low heat to avoid cooking so that farmers typically incur additional inventory costs (Uhrig and Maier, 1992). In addition to moisture levels, other characteristics of hybrid corn, such as time to maturity, resistance to pest and diseases, drought-tolerance, and adaptability to soil quality are captured indirectly through their effects on yields.

To measure income, we follow the standard practice of assuming a price of $2.25 per bushel of corn and a drying cost of $0.04 per percentage point moisture above 15 percent.[28] For example, Pioneer's new hybrid 3375 (USPTO 5,576,472

[28]Price data from the USDA National Agricultural Statistics Service, available at

Figure 2.2: Two Examples of Patents for Hybrid Corn



United States Patent [19] **Roundy**

[11] **Patent Number: 5,576,472**
[45] **Date of Patent: Nov. 19, 1996**

[54] **HYBRID MAIZE PLANT AND SEED (3375)**

[75] Inventor: **Theron E. Roundy**, North Platte, Nebr.

[73] Assignee: **Pioneer Hi-Bred International, Inc.**, Des Moines, Iowa

[21] Appl. No.: **398,471**

[22] Filed: **Mar. 3, 1995**

[51] **Int. Cl.**^{6} **A01H 5/00**; A01H 4/00; A01H 1/00; C12N 5/04

[52] **U.S. Cl.** **800/200**; 800/250; 800/DIG. 56; 435/240.4; 435/240.49; 435/240.5; 47/58; 47/DIG. 1

[58] **Field of Search** .... 800/200, 205, 800/250, DIG. 56; 47/58; 438/240.4, 240.45, 240.49, 240.5

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Phillips, et al. (1988) "Cell/Tissue Culture and In Vitro Manipulation", *Corn & Corn Improvement*, 3rd Ed., ASA Publication, No. 18, pp. 345–387.

Poehlman (1987) *Breeding Field Crop*, AVI Publication Co., Westport, Ct., pp. 237–246.

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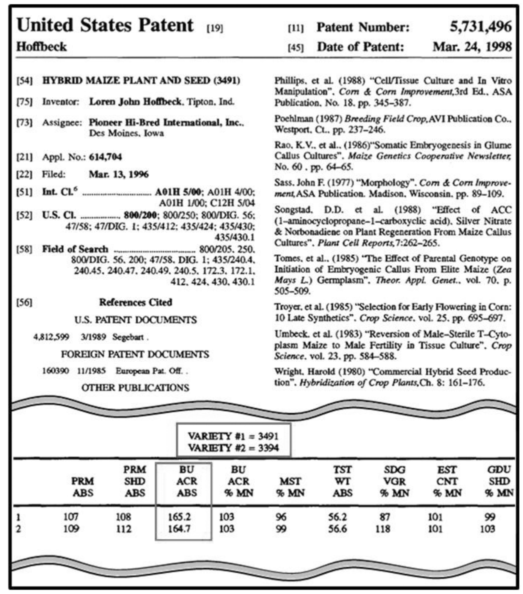
Troyer, et al. (1985) "Selection for Early Flowering in Corn: 10 Late Synthetics", *Crop Science*, vol. 25, pp. 695–697.

Umbeck, et al. (1983) "Reversion of Male–Sterile T–Cytoplasm Maize to Male Fertility in Tissue Culture", *Crop Science*, vol. 23, pp. 584–588.

Wright, Harold (1980) "Commercial Hybrid Seed Production", *Hybridization of Crop Plants*, Ch. 8:161–176.

VARIETY #1 = 3375
VARIETY #2 = 3394

VAR #	BU ACR ABS	BU ACR %MN	MST ABS	TST WT ABS	SDG VGR ABS	EST CNT ABS	TIL LER ABS	GDU SHD ABS
1	181.1	106	21.9	56.4	5.8	53.6	14.1	135.0
2	172.0	100	20.5	56.8	6.7	55.0	2.6	137.5



United States Patent [19] **Hoffbeck**

[11] **Patent Number: 5,731,496**
[45] **Date of Patent: Mar. 24, 1998**

[54] **HYBRID MAIZE PLANT AND SEED (3491)**

[75] Inventor: **Loren John Hoffbeck**, Tipton, Ind.

[73] Assignee: **Pioneer Hi-Bred International, Inc.**, Des Moines, Iowa

[21] Appl. No.: **614,704**

[22] Filed: **Mar. 13, 1996**

[51] **Int. Cl.**^{6} **A01H 5/00**; A01H 4/00; A01H 1/00; C12H 5/04

[52] **U.S. Cl.** **800/200**; 800/250; 800/DIG. 56; 47/58; 47/DIG. 1; 435/412; 435/424; 435/430; 435/430.1

[58] **Field of Search** .... 800/205, 250, 800/DIG. 56, 200; 47/58, DIG. 1; 435/240.4, 240.45, 240.47, 240.49, 240.5, 172.3, 172.1, 412, 424, 430, 430.1

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Poehlman (1987) *Breeding Field Crop*, AVI Publication Co., Westport, Ct., pp. 237–246.

Rao, K.V., et al., (1986) "Somatic Embryogenesis in Glume Callus Cultures", *Maize Genetics Cooperative Newsletter*, No. 60 , pp. 64–65.

Sass, John F. (1977) "Morphology", *Corn & Corn Improvement*, ASA Publication. Madison, Wisconsin, pp. 89–109.

Songstad, D.D. et al. (1988) "Effect of ACC (1–aminocyclopropane–1–carboxylic acid), Silver Nitrate & Norbonadiene on Plant Regeneration From Maize Callus Cultures", *Plant Cell Reports*, 7:262–265.

Tomes, et al., (1985) "The Effect of Parental Genotype on Initiation of Embryogenic Callus From Elite Maize (*Zea Mays L.*) Germplasm", *Theor. Appl. Genet.*, vol. 70, p. 505–509.

Troyer, et al. (1985) "Selection for Early Flowering in Corn: 10 Late Synthetics", *Crop Science*, vol. 25, pp. 695–697.

Umbeck, et al. (1983) "Reversion of Male–Sterile T–Cytoplasm Maize to Male Fertility in Tissue Culture", *Crop Science*, vol. 23, pp. 584–588.

Wright, Harold (1980) "Commercial Hybrid Seed Production", *Hybridization of Crop Plants*, Ch. 8: 161–176.

VARIETY #1 = 3491
VARIETY #2 = 3394

	PRM ABS	PRM SHD ABS	BU ACR ABS	BU ACR % MN	MST % MN	TST WT ABS	SDG VGR % MN	EST CNT % MN	GDU SHD % MN
1	107	108	165.2	103	96	56.2	87	101	99
2	109	112	164.7	103	99	56.6	118	101	103

Notes: Example of 2 out of the 256 patents granted for new hybrids in subclass 800/320.1 Maize between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Included in the patent document are pair-wise comparisons between the newly patented hybrid and an earlier, already established, hybrid. The comparisons include information about the yield of these two hybrids (measured in bushels per acre (in absolute terms) – abbreviated as BU ACR ABS).

granted on November 19, 1996, Figure 2.2, left patent) yields 181.1 bushels per acre and has a moisture level of 21.9 percent. This implies an income per acre of $407.20. In comparison, Pioneer's existing hybrid 3394 yields 172 bushels per acre and has a moisture level of 20.5 percent. This implies an income per acre of $386.78 (Figure 2.2, left patent). Comparing these two hybrid reveals an increase in income per acre of 5.28 percent.

We use two types of comparisons to measure the magnitude of improvements in hybrid corn, self-reported and indirect comparisons. In self-reported comparisons, breeders report field trial comparisons with existing hybrids. For example, Pioneer's new hybrid 3375 (USPTO 5,576,472, Figure 2.2, left patent)

www.nass.usda.gov.

Table 2.2: Improvements in Yield and Income per Acre

	Number of observations	Mean number of comparison hybrids	Share of patents that show an increase in yield per acre	income per acre
All comparisons	256	5.10	41.80	44.14
Direct comparisons	256	2.84	62.89	62.89
Indirect comparisons	172	3.26	34.50	34.88

Notes: An observation consists of a utility patent protecting a new hybrid. Data on yields were collected by a search of patents in subclass 800/320.1 Maize (available at www.uspto.gov). On the patent document breeders compare their new hybrid to existing hybrids to demonstrate that the new hybrid is a patentable improvement. To be patentable, new hybrids must be novel, useful, and non-obvious. To control for improvements in addition to yields, measures of income per acre incorporate information on the moisture content of hybrids. To calculate income, we assume a price of $2.25 per bushel of corn and a drying cost of $0.04 per percentage point moisture above 15% (based on price data from the United States Department of Agriculture's National Agricultural Statistics Service, available at www.nass.usda.gov). Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid.

yields 181.1 bushels per acre. In comparison, Pioneer's existing hybrid 3394 yields 172 bushels per acre (Figure 2.2, left patent). This implies an increase in yields of 5.29 percent.

The data include a total of 726 self-reported comparisons; the average new hybrid is compared with 2.8 existing hybrids in self-reported comparisons (Table 2.2). As a first step, we measure the magnitude of inventions by comparing the new hybrid with the highest-yielding existing hybrid that is listed as a comparison plant.

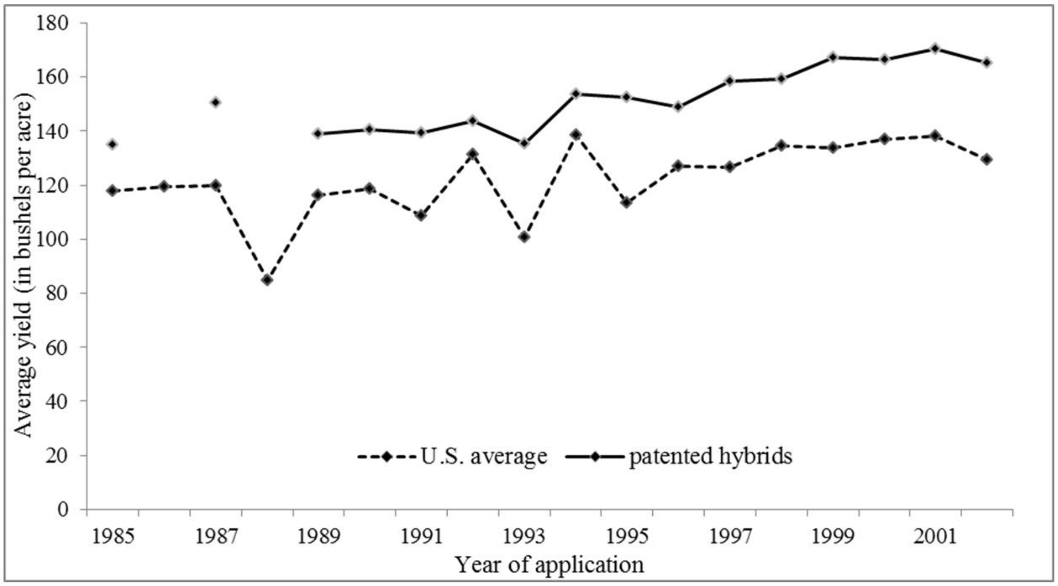
To test whether breeders strategically report comparison plants that maximize the magnitude of the invention that they report to the USPTO we construct an additional set of indirect comparisons that were not reported to the USPTO but can be established by linking the new hybrid through another hybrid with a comparison hybrid that was not reported to the USPTO. For example, Pioneer's hybrid 3491 (USPTO 5,731,496 granted March 13, 1996, Figure 2.2, right patent) yields 165.2 bushels per acre and is compared to Pioneer's hybrid 3394, which yields 164.7 bushels per acre, implying an 0.3 percent increase in yields in self-reported comparisons. Pioneer's hybrid 3375 is also compared to hybrid 3394 (USPTO 5,491,295 granted November 22, 1994, Figure 2.2, left patent), and we use this link to establish an indirect comparison between hybrid 3491 and 3375, which implies that 3491 produces 4.74 less corn than the existing hybrid 3375.[29] We are able to establish a total of 835 indirect comparisons for the 256 new hybrids in our data; on average a new hybrid can be linked with 3.3 existing hybrids in indirect comparisons.

Although breeders may choose the most favorable trial, there is no reason to believe that they would systematically misreport the results of a given trial. The close correspondence in time trends between U.S. average corn yields and reported field trial data (Figure 2.3) also indicate that changes in field trial yields are a good measure of increases in performance.

U.S. averages vary around 120 bushels per acre, while yields in the field trial data remain around 140 bushels per acre, or 15-20 percent higher (Figure 2.3). More generally, changes in yields over time are similar for the matched field trial data and U.S. averages. Yields in field trials fluctuate less across years (with a variance of 144 in field trials, compared with 201 in U.S. averages) because growing conditions are more controlled in the field trials, but changes over time in field trials reported on the patent applications closely mirror changes in U.S. averages.

[29]The relative yield of hybrid 3491 to hybrid 3394 times the relative yield of hybrid 3394 to hybrid 3375 equals (165.2/164.7)*(172.0/181.1) = 0.9526, implying a 4.74 percent decrease in yield.

Figure 2.3: Yields listed on Patent compared with U.S. Averages



Notes: Average yields per year of application for 256 patents granted for new hybrids in subclass 800/320.1 Maize (available at www.uspto.gov). Yields are normalized to 15.5 percent moisture at harvest. Data on yields were collected by a manual search of the full text of patent documents. Data on U.S. averages from the United States Department of Agriculture (www.nass.usda.gov).

New plants are also customarily tested by independent experiment stations. We use data from the annual reports of the Kentucky Hybrid Corn Performance Tests between 1996 and 2009 to verify yields that breeders report on patent documents. Hybrids for 17 direct comparisons were also tested in Kentucky (Figure B.2).[30]

Correlation coefficients between yields on USPTO patents and in Kentucky field trials are 0.44 for yields and 0.38 for income, indicating a significant positive, but imperfect relationship (Figure B.3, B.4). Differences may be due to the fact that field trials are conducted in different locations and under different climatic conditions, so that two field trials for the same plant may not yield the same results. This is less problematic for the self-reported comparisons, which

[30]Experiments are run by the University of Kentucky (www.ca.uky.edu/cornvarietytest/).

compare two plants in the same trial, but creates measurement error for the indirect comparisons, which compare plants across trials.

2.4 Measures of patent quality

2.4.1 Counts of citations by later patents

To measure citation counts for the 256 hybrids in our sample, we search U.S. patents between January 1, 1986 and December 31, 2010 for references to the patent number of the 256 hybrids. This allows us to observe a minimum of 5 years of citations history for each patent.

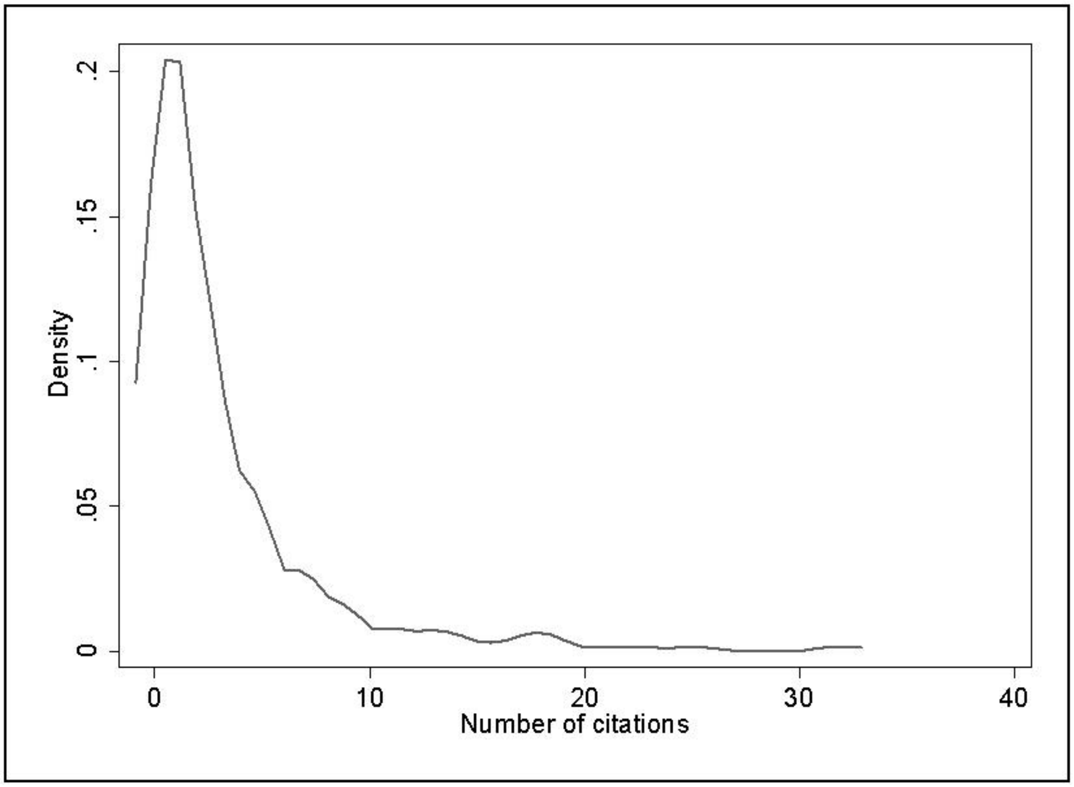
The average patent for hybrid corn receives 7.55 citations between 1985 and 2010 (Table 2.1, Figure 2.4). In comparison, the average patent in NBER patent data (Hall et al., 2001) receives 3.0 citations within the first 5 years after the patent grant, 5.3 citations within 10 years, and 7.3 citations within 25 years.[31]

Five foundational patents are cited more than 100 times each

Two patents, for which DeKalb applied in 1985, are cited 136 and 137 times, respectively. DeKalb's patent USPTO 4,607,453 (filed on February 21, 1985, and granted on August 26, 1986) covers novel F1 hybrid corn plant dk672, novel seeds of the hybrid, seeds produced by cultivation of the hybrid, cells which upon growth and differentiation produce the novel hybrid and a method to

[31]Citations until 2006 are drawn from http://elsa.berkeley.edu/~bhhall/patents.html.

Figure 2.4: Citations per Patent, excluding Outliers



Notes: Data on 251 patents granted for new hybrids in subclass 800/320.1 Maize between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Excluding five patents that received 136, 137, 139, 212 and 551 citations respectively. Data on citations were collected by an automatic search utilizing data available at www.uspto.gov.

produce the novel hybrid. DeKalb's patent 4,629,819 (filed on April 26, 1985, and granted on December 16, 1986) covers novel F1 hybrid corn plants dk524, seeds produced by cultivation of the hybrid, and plant cells which upon growth and differentiation produce the novel hybrid.

Both of these patents are very likely cited so many times because they were the first patents after *re Hibberd* that were granted by the USPTO, and they are cited independently of their yields and other characteristics. In fact, most DeKalb patents cite Hibberd's patent along with the early patents that were issued to DeKalb to establish the patentability of their inventions. After 1985, DeKalb did not apply for any additional patents for hybrid corn until 1990, when it applied for one patent (Figure 2.6, USPTO 5,589,605, granted on December 31, 1996 for hybrid EXP 748). Similarly, two patents for which Pioneer applied for in 1987, seven years before the company begins to patent systematically, receive a large number of citations. Pioneer's first patent USPTO 4,731,499 (for Pioneer hybrid 3790, granted on March 15, 1988) is the most cited patent in our data, with a total of 551 citations:

Patent number:	4,731,499
Title:	Hybrid corn plant and seed
Date issued:	March 15, 1988
Date filed:	January 29, 1987
Inventors:	Carrigan; Lori (New London, MN); Puskaric; Vladimir (Woodstock, CA)
Assignee:	Pioneer Hi-Bred International, Inc. (Johnston, IA)
Abstract:	According to the invention, there is provided a hybrid corn plant, designated 3790, produced by crossing two Pioneer Hi-Bred International, Inc. proprietary inbred lines of corn. This invention thus relates to the hybrid seed 3790, the hybrid plant produced from the seed, variants, mutants, and modifications of Pioneer hybrid 3790. This hybrid corn plant is characterized by superior yields and excellent early-season cold tolerance, and good grain quality.

Claims: What is claimed is: 1. Hybrid corn seed designated 3790. 2. A hybrid corn plant and its plant parts produced by the seed of claim 1. 3. Corn plants and the seed thereof regenerated from tissue culture of the hybrid corn plant and plant parts of claim 2. 4. A hybrid corn plant with the phenotypic characteristics of the hybrid plant of claim 2.

In a section entitled "background," this patent application includes a description of the process of breeding hybrid corn; nearly all patents for corn hybrids that follow it include a similar description. Pioneer's second patent in 1987, USPTO 4,737,596 (for Pioneer hybrid 3471, produced by crossing two proprietary Pioneer inbred corn lines, granted on January 29, 1987), is cited by 139 later patents. This patent, as well as nearly all other patents, includes the same description of the corn breeding process as Pioneer's foundational patent for hybrid 3470. USPTO patent 6,433,261, for the inbred corn plant 89AHD12 and "hybrid genetic complements of the inbred corn plant 89AHD12", received 212 citations.

2.4.2 Claims as a measure for the scope of patents

Claims, which define the scope of protection by specifying the matter that is subject to the utility patent, have been proposed as another measure for the quality of innovations (e.g. Lanjouw and Schankerman, 2004). While other types of intellectual property rights cover only one claim (plant patents for asexually reproduced plants under the PP Act of 1930) or no claims (under the PVP Act of 1970), utility patents can include a large number of claims. Each utility

Table 2.3: Renewal Decisions

	Number of observations	Share of patents that are renewed
4 years after the patent grant	256	98.05 %
8 years after the patent grant	224	97.32 %
12 years after the patent grant	71	92.96 %

Notes: Data include renewals up to 2010. This leads to truncation: Renewals after 12 years are observable only for patents granted up to 1998. Renewals after 8 years are observable only for patents granted up to 2002. Patent and renewal fee data from the USPTO.

patent includes at least one claim, which typically covers the seed of the plant, as well as plants with the phenotypic characteristics of plant grown from that seed.[32] Additional claims cover plant traits, such as heat tolerance and disease resistance, breeding methods, or characteristics as a food product. We include claims as a measure for the scope of patents in regressions of citations counts on improvements in yields and other characteristics of hybrid corn.

2.4.3 Renewal decisions

As mentioned above, patent renewal decisions have been suggested as an alternative measure for the quality of patented inventions. Nearly all patents in our data were renewed to full term (Table 2.3).[33] The USPTO introduced renewal fees to keep patents active on December 11, 1980. Renewal fees are $980 to keep

[32]Breeders deposit specimen of these seeds with the American Type Culture Collection (ATCC) "an independent, private, nonprofit biological resource center (BRC) and research organization whose mission focuses on the acquisition, authentication, production, preservation, development and distribution of standard reference microorganisms, cell lines and other materials for research in the life sciences." http://www.atcc.org/About/tabid/138/Default.aspx (assessed on 12/02/2011).

[33]Data on renewal fees and renewal decisions from www.uspto.gov.

a patent active at 4 years after the grant, $2,480 at 8 years, and $4,110 at 11 years. Among 256 patents of hybrid corn in our data, only 71 patents were at least 12 years old in 2011 and could have been renewed for the full term; 66 of these patents (93 percent), were renewed to full term. A total of 224 patents were at least 8 years old in 2011; 218 of these patents (97 percent) were renewed after 8 years; 251 patents (98 percent) were renewed after 4 years (Table 2.3).

Thus, nearly all patents were renewed to full term, with the exception of three early DeKalb patents (including one of the company's heavily cited foundational patents) and two patents by Kleinwanzlebener Saatzucht AG, a small German breeder. Three of the five patents that were never renewed are patents that the USPTO granted to DeKalb in 1995 (before DeKalb had been acquired by Monsanto on May 11, 1998): USPTO 5,436,389 granted on July 25, 1995, USPTO 5,444,177 granted on August 22, 1995, and USPTO 5,451,705 granted on September 19, 1995. DeKalb's foundational patent USPTO 4,629,819 (granted on December 16, 1986) received 137 citations, and was renewed at 4 and 8, but not 12 years. Only two additional patents, for dent corn hybrids, assigned to the German Kleinwanzlebener Saatzucht AG were not renewed for the full term: USPTO 5,929,312 granted on July 27, 1999 and USPTO 6,127,608 granted on October 3, 2000.

2.5 Results

2.5.1 Improvements over the prior art

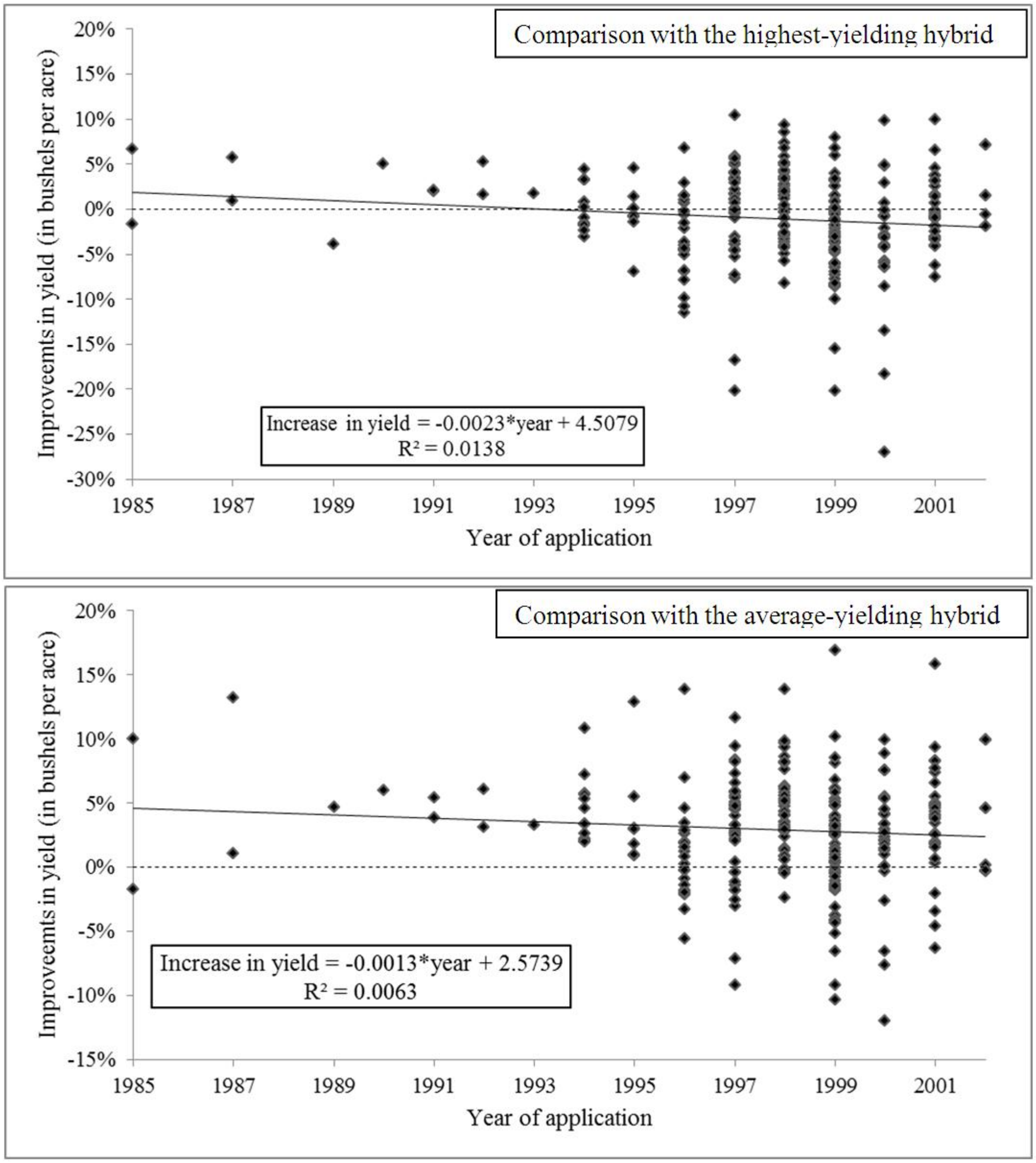
Of 256 patented corn hybrids, only 107 (or 42 percent) produced more corn than existing hybrids (Table 2.2). The largest improvement in yields is 10 percent, but the data also include a hybrid that produces 25 percent less than existing hybrids (Figure 2.5). Data on improvements in income per acre confirm the relatively small magnitude of inventive output. Only 113 of 256 new hybrids (or 44 percent) produce more income than existing hybrids (Table 2.2).

These findings are robust across examiners and assignees. A total of nine primary patent examiners granted the 256 patents in our sample; two examiners granted 189 and 34 patents, respectively (Table 2.4). Estimates for the size of improvements are roughly comparable across examiners.

Patents are assigned to eight different breeders. The top two breeders, Pioneer and DeKalb, produced 129 and 110 respectively (Table 2.5). For Pioneer, the estimates for the average magnitude of inventive output are negative, with -2.4 percent for yields and -2.2 percent for income. In comparison, estimates for DeKalb/Monsanto are close to zero and slightly positive for yields, at 0.3 percent, and slightly negative for income at -0.1 percent. For both firms, the magnitude of improvements declines over time (Figure 2.6).

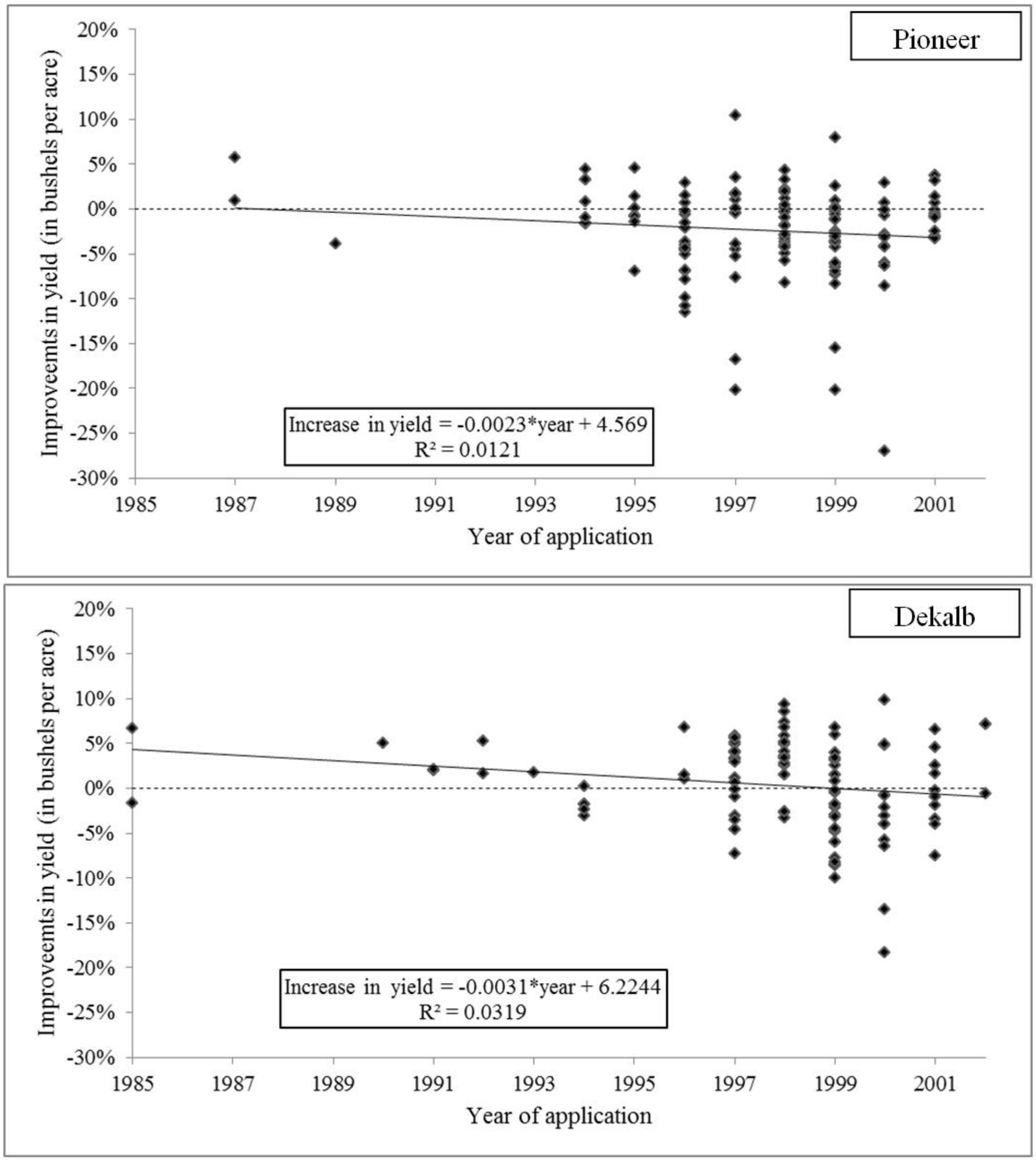
The data also reveal a decline in the magnitude of inventions over time. The gradual nature of this decline is consistent with the idea that yields approach a natural upper limit. For example, there is no evidence of a trend break in the years of Monsanto's aggressive acquisition policies (1994-1996) even though the

Figure 2.5: Improvements in Yields listed on new Patents by Year of Application



Notes: Improvements in yields are calculated by comparing the yield of the new hybrid with the highest-yielding (top figure) or average-yielding hybrid (bottom figure) with similar characteristics. Calculations include both direct and indirect comparisons. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. Data on all 256 patents in subclass 800/320.1 Maize granted between January 1, 1985 and March 8, 2005 (available at www.uspto.gov).

Figure 2.6: Improvements in Yields - Pioneer and DeKalb



Notes: Improvements in yields are calculated by comparing the yield of the new hybrid with the highest-yielding hybrid with similar characteristics. Calculations include both direct and indirect comparisons. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. Data on all 129 patents in subclass 800/320.1 Maize granted between January 1, 1985 and March 8, 2005 assigned to Pioneer and all 110 patents assigned to DeKalb Genetics (available at www.uspto.gov).

Table 2.4: Improvements in Yield and Income per Acre by Patent Examiner

Patent examiner	Number of observations	Average percentage increase in yield per acre	income per acre
Examiner A	189	-1.24	-1.25
Examiner B	34	-1.57	-1.12
Examiner C	19	-0.12	0.52
Examiner D	5	1.10	1.92
Examiner E	4	2.90	2.88
Examiner F	2	1.51	0.74
Examiner G	1	-0.90	-1.72
Examiner H	1	-4.06	-4.28
Examiner I	1	3.23	1.92
Weighted average	-	-1.06	-0.96

Notes: An observation consists of a utility patent protecting a new hybrid. Data on yields were collected by a search of patents in subclass 800/320.1 Maize (available at www.uspto.gov). Information on the primary patent examiner was obtained through an automated search. On the patent document breeders compare their new hybrid to existing hybrids to demonstrate that the new hybrid is a patentable improvement. To control for improvements in addition to yields, measures of income per acre incorporate information on the moisture content of hybrids. To calculate income, we assume a price of $2.25 per bushel of corn and a drying cost of $0.04 per percentage point moisture above 15% (based on price data from the United States Department of Agriculture's National Agricultural Statistics Service, available at www.nass.usda.gov).

absolute number of patents increased dramatically during this period.

2.5.2 Strategic reporting

We find that breeders choose comparison plants that magnify the size of the improvement over the prior art. Data for 172 indirect comparisons, which we establish by linking new hybrids to other hybrids not reported on the patent, suggest that only 35 percent of new hybrids produce more corn or income than existing hybrids (Table 2.2). Although indirect comparisons are likely to be measured with some error, these results are suggestive. Comparisons of the distribution of self-reported and indirect comparisons confirm that breeders consis-

Table 2.5: Improvements in Yield and Income per Acre by Assignee

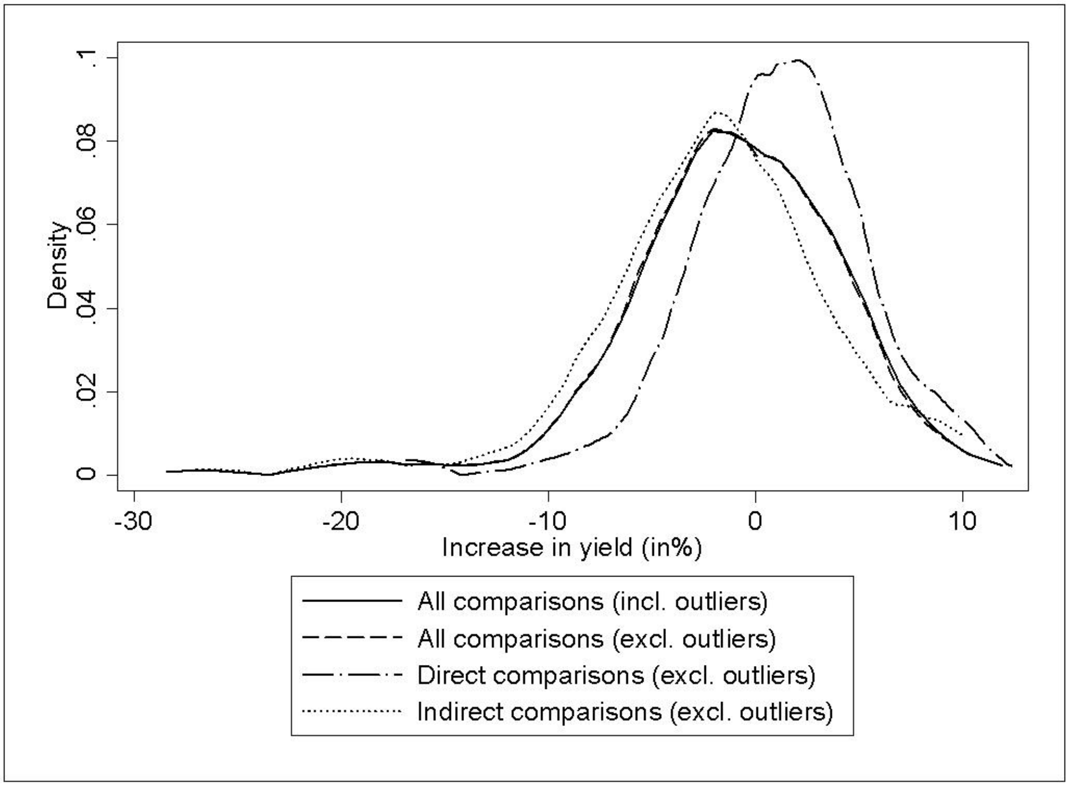
Name of assignee	Number of observations	Average percentage increase in yield per acre	income per acre
Pioneer	129	-2.40	-2.22
Dekalb Genetics [1)]	110	0.33	-0.07
Asgrow [1)]	8	-1.34	-0.13
Rustica Prograin Genetique	3	-2.90	0.18
Kleinwanzlebener Saatzucht	2	2.75	1.56
Monsanto [1)]	2	1.48	0.65
Euralis	1	9.93	10.30
Sandoz	1	3.33	7.30
Weighted average	-	-1.06	-1.06

Notes: 1) Monsanto acquired Asgrow in 1997 and DeKalb Genetics in 1998. An observation consists of a utility patent protecting a new hybrid. Data on yields were collected by a search of patents in subclass 800/320.1 Maize (available at www.uspto.gov). Information on the assignee was obtained through an automated search. On the patent document breeders compare their new hybrid to existing hybrids to demonstrate that the new hybrid is a patentable improvement. To control for improvements in addition to yields, measures of income per acre incorporate information on the moisture content of hybrids. To calculate income, we assume a price of $2.25 per bushel of corn and a drying cost of $0.04 per percentage point moisture above 15% (based on price data from the United States Department of Agriculture's National Agricultural Statistics Service, available at www.nass.usda.gov).

tently choose comparison plants that increase the magnitude of their improvement over existing hybrids (Figure 2.7).

There is no evidence of statistically significant differences over time between self-reported and indirect comparisons; both series exhibit a decline over time from about 6 percent in 1989 to -4 percent in 2000 (Figures A5 and A6).

Figure 2.7: Increase in Yield per Acre

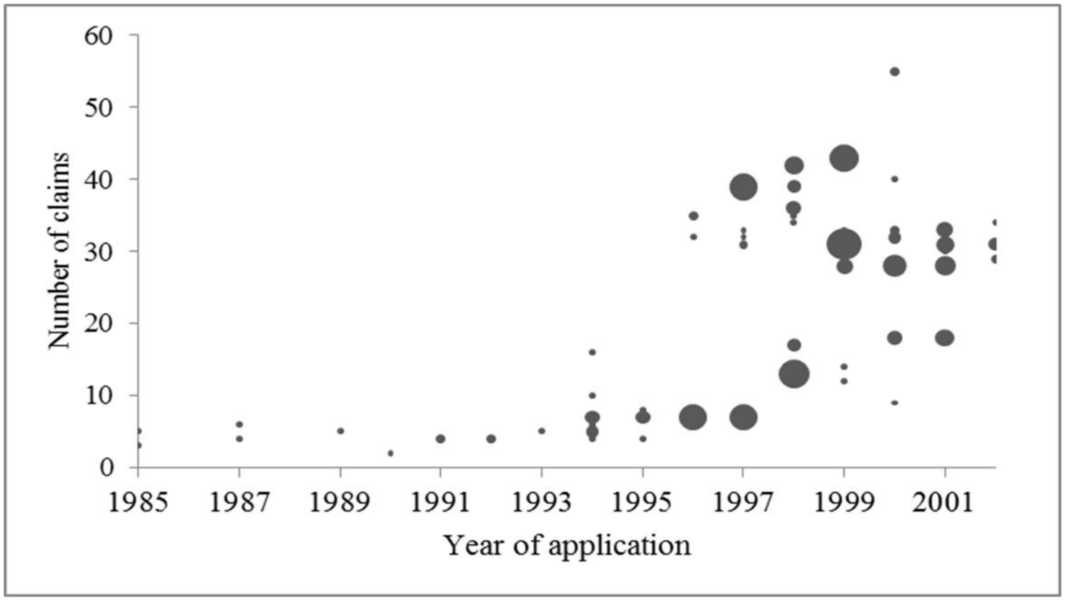


Notes: Data on 256 patents granted for new hybrids in subclass 800/320.1 Maize between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Improvements in yields are calculated by comparing the yield of the new hybrid with the highest-yielding hybrid with similar characteristics. Calculations include both direct and indirect comparisons. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. Excluding five patents that received 136, 137, 139, 212 and 551 citations respectively.

2.5.3 Claims

Data on claims indicate that the number of claims varies across firms, and increases over time. Across all years and breeders, the average patent includes 24.22 claims (Table 2.1). Over time, the mean number of claims per patent increases from 6.71 in 1985 to 30.86 in 2002 (Figure 2.8). Breeders appear to develop templates for their claims and expand their templates to add new claims

Figure 2.8: Number of Claims by Year of Application

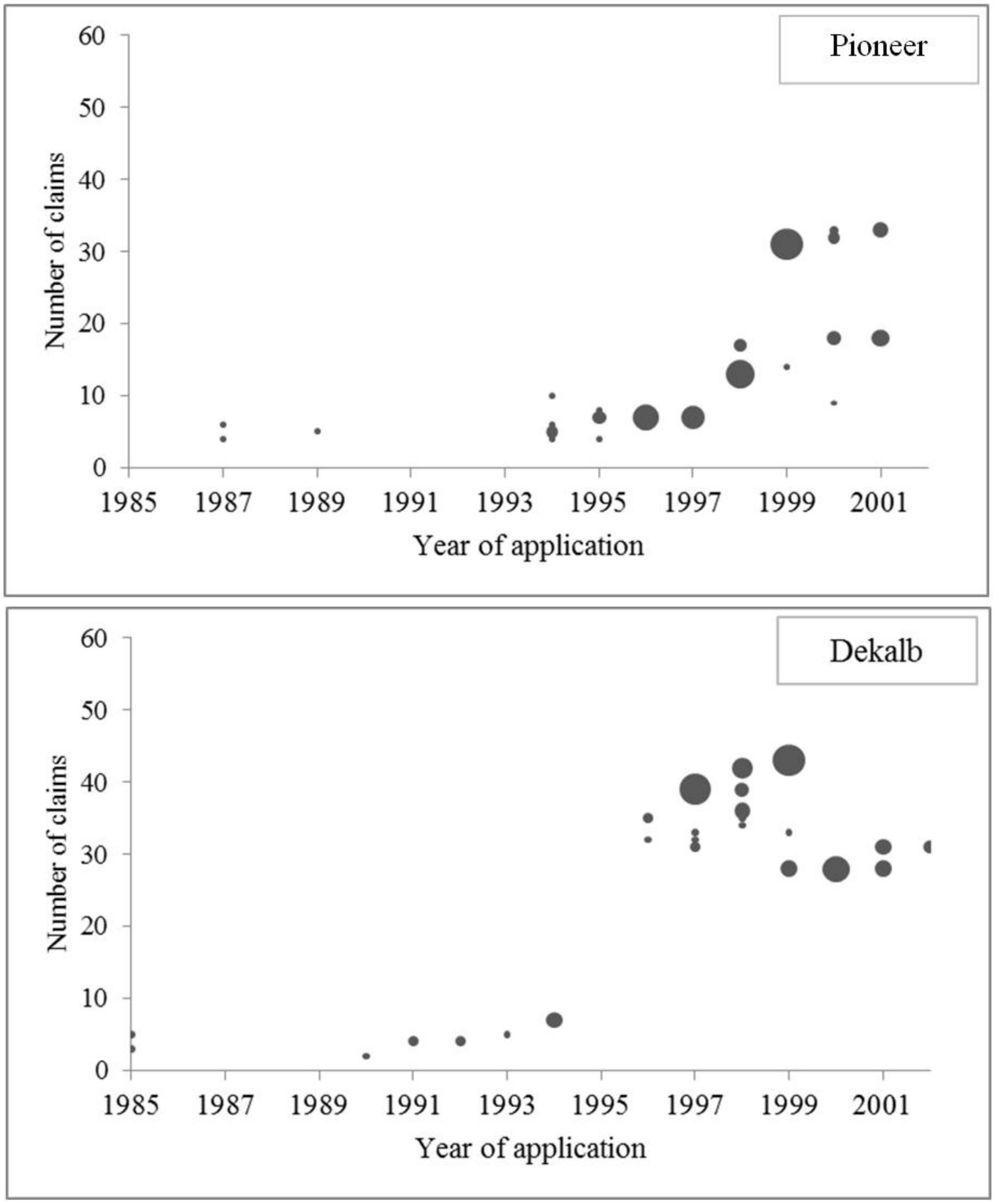


Notes: Bubble size represents the number of observations ranging from 1 to 25. For example: there are 25 patents each having 31 claims in 1999. Data on all 256 patents granted for new hybrids in subclass 800/320.1 Maize granted between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Data on claims were collected by a manual search of the full text of patent documents.

over time. The average patent of DeKalb includes 32.27 claims; which cover the inbred parents of the hybrid, along with the hybrid itself, which is the main subject matter of the patent (Figure 2.9). In comparison, the average patent of Pioneer covers roughly half the number of claims, at 16.58 claims per patent, which typically only cover the hybrid itself, and not its inbred parents. 102 of DeKalb's 110 patents cover inbred parents, in addition to the hybrid seed.

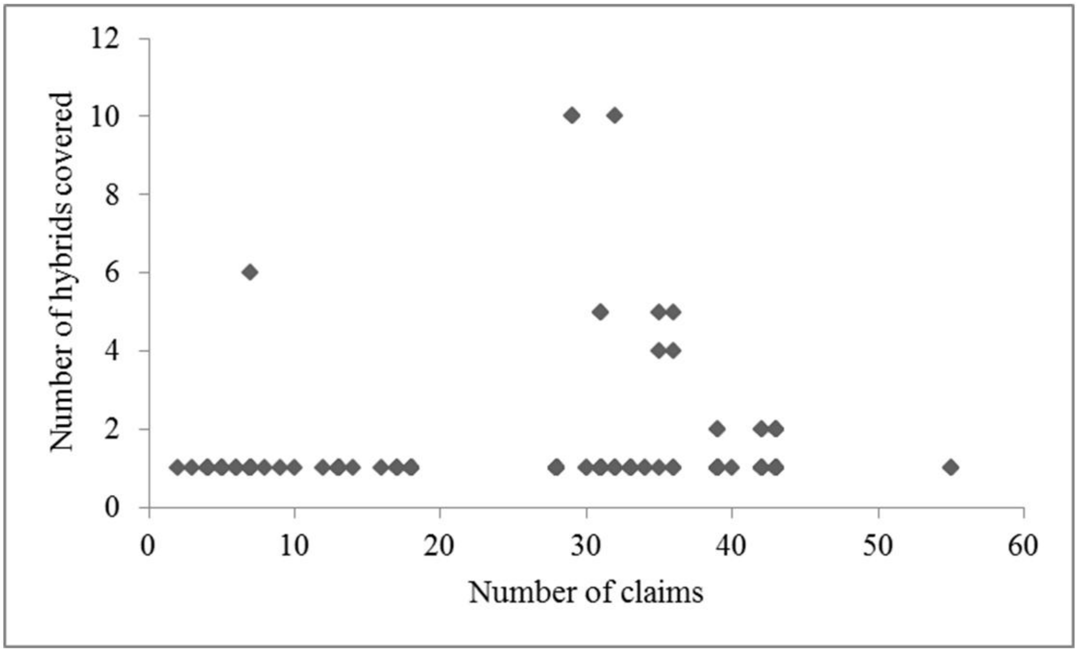
Claims are only weakly correlated with the number of hybrids covered by the same patent (Figure 2.10). A total of 19 in 256 patents (7.42 percent) protect more than one hybrid; the average patent protects 1.25 hybrids. Across all hybrids, the correlation between claims and the number of hybrids that are pro-

Figure 2.9: Number of Claims by Year of Application - Pioneer and Dekalb



Notes: Bubble size represents the number of observations ranging from 1 to 25. For example: there are 25 patents by Pioneer each having 31 claims in 1999. Data on all 129 patents in subclass 800/320.1 Maize granted between January 1, 1985 and March 8, 2005 assigned to Pioneer and all 110 patents assigned to Dekalb Genetics (available at www.uspto.gov). Data on claims were collected by a manual search of the full text of patent documents.

Figure 2.10: Number of Hybrids covered versus Number of Claims

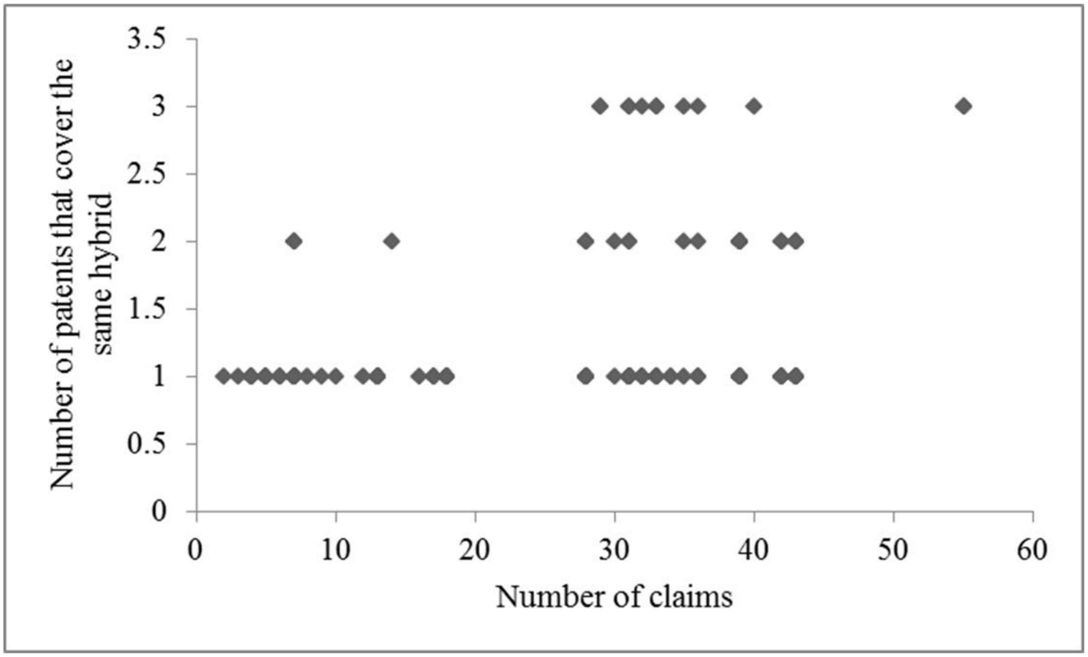


Notes: Data on all 256 patents in subclass 800/320.1 Maize granted between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Data on claims were collected by a manual search of the full text of patent documents.

tected by a patent is 0.1111. Eighteen of the 19 patents that protect multiple hybrids are assigned to DeKalb; the remaining patent is assigned to the French seed company Euralis.

The data also indicate that claims are positively correlated with the number of patents that cover the same hybrid (Figure 2.11). Forty of 256 patented corn hybrids (16 percent) are covered by two or more patents; the average hybrid is covered by 1.20 patents, 28 hybrids are covered by 2 patents, 12 hybrids are covered by 3 patents. Across all hybrids, the correlation between claims and the number of patents that cover the same hybrid is 0.3155. Thirty-five of the 40 patents are assigned to DeKalb, 3 patents to Rustica Prograin Genetique and 2 to Pioneer. The correlation between claims and the number of DeKalb patents that cover the same hybrid is 0.0922.

Figure 2.11: Number of Patents that cover the same Hybrids versus Number of Claims



Notes: Data on all 256 patents in subclass 800/320.1 Maize granted between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Data on claims were collected by a manual search of the full text of patent documents.

Overall, the data suggest that claims and the structure of patents (number of patents covering the same hybrid and number of hybrids covered by the same patent) are specific to breeders, who follow their own, firm-specific templates of patent applications, and may therefore contain only limited information regarding the scope of patents, at least for hybrid corn.

2.5.4 Relationship between citations and the magnitude of inventive output

OLS and negative binomial regressions estimate the correlation between citations and the size of improvements in yields and other characteristics, using claims to control for the scope of patents and allowing for year and firm fixed effects:

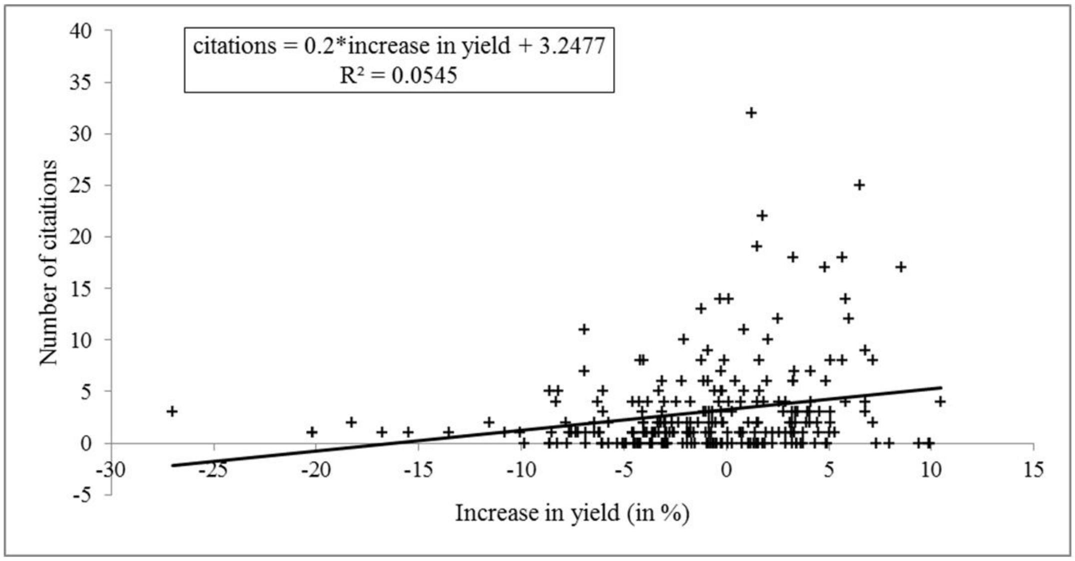
$$\begin{aligned} Citation_i &= \alpha + \beta_1 Increase\ in\ yields_i + \beta_2 Claims_i \\ &\quad + \gamma Z_i + \delta_i + \beta_3 DeKalb_i + \beta_4 Other\ firm_i + \epsilon_i \end{aligned}$$

where *Citations* counts the number of later patents that cite one of the 256 patents for corn hybrids, *Increase in yields* measures the percent increase in yields that the newly patented hybrid offers over existing hybrids, and *Claims* counts the number of claims that define the scope of the patent. The variable δ indicates year fixed effects, *DeKalb* distinguishes patents assigned to DeKalb, and *Other firms* denotes patents that are neither assigned to DeKalb or Pioneer, which is the excluded category. 129 out of the 256 patents (30 percent) in our data are assigned to Pioneer.

Comparisons between citations counts and increases in yields indicate a strong positive correlation (Figure 2.12). OLS and negative binomial regressions with additional controls for the number of claims of a patent, the number of hybrids covered by the patent, the number of other patents covering a hybrid, year of application, firm and/or year fixed effects, confirm these results (Table 2.6).[34]

[34]We estimate negative binomial regressions instead of Poisson to account for over-dispersion in the dependent variable. If two regressors in a count data model are collinear for the subsample of positive observations of the dependent variable, maximum-likelihood estimates may yield spurious estimates (Santos-Silva and Tenreyro 2009). We checked whether any pair of

Figure 2.12: Increase in Yield per Acre versus Number of Citations, excluding Outliers



Notes: Data on 256 patents granted for new hybrids in subclass 800/320.1 Maize between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Improvements in yields are calculated by comparing the yield of the new hybrid with the highest-yielding hybrid with similar characteristics. Calculations include both direct and indirect comparisons. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. Excluding five patents that received 136, 137, 139, 212 and 551 citations respectively. Data on citations were collected by an automatic search utilizing data available at www.uspto.gov.

In negative binomial regressions on a restricted sample (excluding the five outlier patents that receive over 100 each) with firm- and year-fixed effects, a 10 percentage point increase in yields is associated with a 1.9 additional citations (Table 2.7, column 1, significant at the 1 percent level), and a 10 percentage point

regressors in the subsample of observations with a strictly positive number of citations are collinear, and found no evidence of collinearity. Out of 110 patents assigned to DeKalb, 102 patents also cover the hybrid's parent inbred in addition to the new hybrid. In addition to the reported regressions, we run the specification reported in column (3) and (4) with an additional dummy variable controlling for whether or not a parent inbred is also covered. Neither the coefficients on the percentage increase in yield (up to 3 digits of precision) nor the significance levels are changed due to the inclusion of the extra dummy variable.

Table 2.6: Citations as a Function of *Yields per Acre*, dependent Variable is Citations per Patent, *full Sample*

		Full sample		DeKalb only		Full sample		DeKalb only
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Neg. Bin.	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS	OLS	OLS	OLS
% increase in yield per acre	0.521***	0.559**	0.518***	1.067**	0.491**	0.485	0.442***	0.690*
	(0.172)	(0.285)	(0.159)	(0.452)	(0.197)	(0.309)	(0.165)	(0.404)
# of claims	-0.004	-0.013			-0.166	0.524		
	(0.114)	(0.113)			(0.153)	(0.368)		
# of hybrids covered by this patent			-0.104	-1.390			-0.386	-0.581*
			(0.628)	(1.033)			(0.312)	(0.305)
# of other patents covering this hybrid			1.649	1.964			0.552	0.314
			(1.520)	(2.200)			(0.898)	(1.284)
Year of application		-0.841**				-34.522**		
		(0.368)				(13.543)		
Year of application ^{2}						1.327**		
						(0.495)		
DeKalb	1.461	2.547	0.780		4.319	-12.201	1.853	
	(2.233)	(3.058)	(1.677)		(4.237)	(10.652)	(2.478)	
Other firm	-11.764***	-3.909*	-13.077***		-3.646*	-18.890**	-5.517**	
	(4.222)	(2.258)	(4.671)		(1.922)	(8.017)	(2.582)	
Time fixed effects	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Log likelihood	-578.951	-627.712	-578.380	-283.135	-1159.751	-1239.276	-1160.022	-484.713
Pseudo R^2	0.145	0.073	0.146	0.101				
R^2					0.676	0.396	0.675	0.458
N	256	256	256	110	256	256	256	110

Average marginal effects. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$

Notes: Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 available at www.uspto.gov. Year of application and (Year of application)^2 control for linear and quadratic time trends using 1985 as the base year. Time fixed effects measure application year fixed effects for the full sample (columns 1-3, and 5-8); for regressions of DeKalb data only, two-year dummies are used.

increase in income is associated with 2.5 additional citations (Table 2.9, column 1, significant at the 1 percent level) when the comparison is made with respect to the *highest-yielding* comparison hybrid. A 10 percentage point increase in yields is associated with 2.4 additional citations when the comparison is made with respect to the *average* comparison hybrid (Table 2.8, column 1, significant at the 1 percent level). These results are robust to alternative specifications as OLS (Tables 2.7 to 2.9, column 5, significant at the 1 percent level), as well as the inclusion of linear and quadratic time trends (Tables 2.7 to 2.9, columns 2 and 6, significant at the 1 percent level). Considering *direct* (i.e. self-reported) and *indirect comparisons* separately, the coefficient on percentage increases in yield or income is consistently positive and significant (Table 2.10).

Coefficient estimates for the number of claims are not significant at the 10 percent level in any specification (Table 2.6 to 2.10). In addition to the number of claims, which is a measure of the scope of a patent, we also use the number of hybrids covered by the patent as well as the number of other hybrids covering the patented hybrid as alternative measures for the scope of a patent. Both variables are not significant the 10 percent level (Table 2.6 to 2.9, columns (3) and (7)). Since Pioneer patents do not show any variation in the number of hybrids covered (always equal to 1) or the number of other patents covering the same hybrid (always equal to zero), we ran the same regressions for a subset of our data set, including only patents assigned to DeKalb. The coefficient on the percentage increase in yield or income remains positive and significant, but becomes larger (Table 2.7 to 2.9, columns (4) and (8)).

Estimates in the data set including the outlier patents are substantially larger, implying between 4 and 6 additional citations (Table 2.6, Full sample).

Table 2.7: Citations as a Function of *Yields per Acre*, dependent Variable is Citations per Patent, *excluding Outlier Patents*

		Full sample		DeKalb only		Full sample		DeKalb only
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Neg. Bin.	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS	OLS	OLS	OLS
% increase in yield per acre	0.191***	0.187***	0.207***	0.373***	0.195***	0.182***	0.212***	0.322***
	(0.061)	(0.056)	(0.059)	(0.121)	(0.057)	(0.052)	(0.056)	(0.118)
# of claims	0.041	0.022			0.037	0.035		
	(0.042)	(0.032)			(0.038)	(0.034)		
# of hybrids covered by this patent			-0.085	-0.586			-0.211	-0.489*
			(0.229)	(0.434)			(0.188)	(0.298)
# of other patents covering this hybrid			0.857	1.198			0.978	1.073
			(0.605)	(0.933)			(0.652)	(0.955)
Year of application		0.053				-1.030		
		(0.138)				(0.798)		
Year of application ^{2}						0.043		
						(0.032)		
DeKalb	-0.529	0.337	-0.233		-0.307	0.255	-0.011	
	(0.697)	(0.658)	(0.589)		(0.759)	(0.768)	(0.649)	
Other firm	-3.744***	-2.748***	-3.794***		-2.958***	-2.567***	-3.018***	
	(1.127)	(0.965)	(1.104)		(0.741)	(0.679)	(0.786)	
Time fixed effects	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Log likelihood	-530.536	-543.046	-529.984	-250.339	-704.102	-719.916	-703.351	-327.747
Pseudo R^2	0.047	0.025	0.048	0.045				
R^2					0.195	0.086	0.199	0.135
N	251	251	251	107	251	251	251	107

Average marginal effects. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$

Notes: Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 available at www.uspto.gov. Excluding five patents that received 136, 137, 139, 212 and 551 citations respectively. Year of application and (Year of application)² control for linear and quadratic time trends using 1985 as the base year. Time fixed effects measure application year fixed effects for the full sample (columns 1-3, and 5-8); for regressions of DeKalb data only, two-year dummies are used.

Table 2.8: Citations as a Function of *Yields per Acre*, Comparison with the *average-yielding Hybrid*, dependent Variable is Citations per Patent, *excluding Outlier Patents*

		Full sample		DeKalb only		Full sample		DeKalb only
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Neg. Bin.	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS	OLS	OLS	OLS
% increase in yield per acre	0.239***	0.232***	0.258***	0.398***	0.225***	0.208***	0.244***	0.339***
	(0.059)	(0.058)	(0.061)	(0.127)	(0.056)	(0.054)	(0.055)	(0.114)
# of claims	0.043	0.025			0.039	0.033		
	(0.042)	(0.033)			(0.039)	(0.035)		
# of hybrids covered by this patent			-0.169	-0.810*			-0.254	-0.636**
			(0.247)	(0.457)			(0.192)	(0.289)
# of other patents covering this hybrid			0.802	1.367			0.865	1.235
			(0.652)	(0.981)			(0.665)	(0.971)
Year of application		0.020				-0.972		
		(0.146)				(0.831)		
Year of application ^{2}						0.040		
						(0.033)		
DeKalb	-0.195	0.730	0.217		0.020	0.636	0.431	
	(0.720)	(0.693)	(0.617)		(0.784)	(0.806)	(0.673)	
Other firm	-3.928***	-2.742**	-3.843***		-3.148***	-2.592***	-3.077***	
	(1.136)	(0.993)	(1.142)		(0.762)	(0.711)	(0.822)	
Time fixed effects	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Log likelihood	-529.554	-543.042	-529.251	-251.158	-704.053	-720.298	-703.538	-328.262
Pseudo R^2	0.049	0.025	0.049	0.041				
R^2					0.195	0.084	0.198	0.127
N	251	251	251	107	251	251	251	107

Average marginal effects. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$

Notes: Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 available at www.uspto.gov. Excluding five patents that received 136, 137, 139, 212 and 551 citations respectively. Year of application and (Year of application)^2 control for linear and quadratic time trends using 1985 as the base year. Time fixed effects measure application year fixed effects for the full sample (columns 1-3, and 5-8); for regressions of DeKalb data only, two-year dummies are used.

Table 2.9: Citations as a Function of *Income per Acre*, dependent Variable is Citations per Patent, *excluding Outlier Patents*

	(1)	Full sample (2)	(3)	DeKalb only (4)	(5)	Full sample (6)	(7)	DeKalb only (8)
	Neg. Bin.	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS	OLS	OLS	OLS
% increase in income per acre	0.253***	0.220***	0.260***	0.379***	0.244***	0.218***	0.254***	0.326***
	(0.071)	(0.061)	(0.065)	(0.118)	(0.063)	(0.059)	(0.061)	(0.118)
# of claims	0.013	0.009			0.018	0.024		
	(0.042)	(0.031)			(0.038)	(0.034)		
# of hybrids covered by this patent			-0.092	-0.637			-0.192	-0.491*
			(0.230)	(0.422)			(0.188)	(0.285)
# of other patents covering this hybrid			0.928	1.385			0.929	1.086
			(0.581)	(0.917)			(0.653)	(0.959)
Year of application		0.104				-0.922		
		(0.135)				(0.786)		
Year of application ^{2}						0.040		
						(0.032)		
DeKalb	-0.151	0.620	-0.295		-0.020	0.445	0.002	
	(0.695)	(0.672)	(0.552)		(0.771)	(0.779)	(0.634)	
Other firm	-3.707***	-2.894***	-4.150***		-3.089***	-2.825***	-3.362***	
	(1.094)	(0.981)	(1.105)		(0.752)	(0.708)	(0.799)	
Time fixed effects	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Log likelihood	-526.380	-540.803	-525.089	-249.480	-701.245	-717.990	-700.210	-327.439
Pseudo R^2	0.055	0.029	0.057	0.048				
R^2					0.213	0.100	0.219	0.140
N	251	251	251	107	251	251	251	107

Average marginal effects. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$

Notes: Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 available at www.uspto.gov. Excluding five patents that received 136, 137, 139, 212 and 551 citations respectively. Data on income per acre incorporate information on the moisture content of a new hybrid in addition to its yield. Calculations use \$2.25 per bushel of corn and drying costs of \$0.04 per percent moisture above 15%. Price data from the United States Department of Agriculture's National Agricultural Statistics Service, available at www.nass.usda.gov. Year of application and (Year of application)^2 control for linear and quadratic time trends using 1985 as the base year. Time fixed effects measure application year fixed effects for the full sample (columns 1-3, and 5-8); for regressions of DeKalb data only, two-year dummies are used.

Table 2.10: Citations as a Function of *Yields per Acre*, *direct and indirect Comparisons*, dependent Variable is Citations per Patent, *excluding Outlier Patents*

	Direct comparisons					Indirect comparisons		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS
% increase in yield per acre	0.189***	0.167***	0.183***	0.156***	0.098**	0.116**	0.092*	0.118*
	(0.060)	(0.059)	(0.060)	(0.055)	(0.049)	(0.048)	(0.047)	(0.062)
# of claims	-0.045	-0.018		-0.021	-0.026	-0.011		-0.014
	(0.040)	(0.031)		(0.029)	(0.041)	(0.030)		(0.031)
# of hybrids covered by this patent			-0.343				-0.129	
			(0.294)				(0.281)	
# of other patents covering this hybrid			0.842*				0.769	
			(0.512)				(0.520)	
Year of application		0.191				0.212		
		(0.149)				(0.144)		
DeKalb	0.012	0.544	-0.656	-0.036	0.034	0.568	-0.535	0.061
	(0.667)	(0.693)	(0.533)	(0.827)	(0.707)	(0.652)	(0.534)	(0.857)
Other firm	-2.727***	-2.137**	-3.682***	-2.534***	-2.359**	-1.729**	-3.200***	-2.359**
	(1.005)	(0.882)	(1.118)	(0.907)	(1.028)	(0.840)	(1.070)	(0.952)
Time fixed effects	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Log likelihood	-329.355	-344.170	-329.051	-430.599	-331.905	-344.124	-331.432	-430.997
Pseudo R^2	0.060	0.018	0.061		0.053	0.018	0.054	
R^2				0.287				0.283
N	170	170	170	170	170	170	170	170

Average marginal effects. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$

Notes: Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 available at www.uspto.gov. Excluding five patents that received 136, 137, 139, 212 and 551 citations respectively. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. Year of application and (Year of application)^2 control for linear and quadratic time trends using 1985 as the base year. Time fixed effects measure application year fixed effects for the full sample (columns 1-3, and 5-8); for regressions of DeKalb data only, two-year dummies are used.

Other characteristics: Suitability to different climates

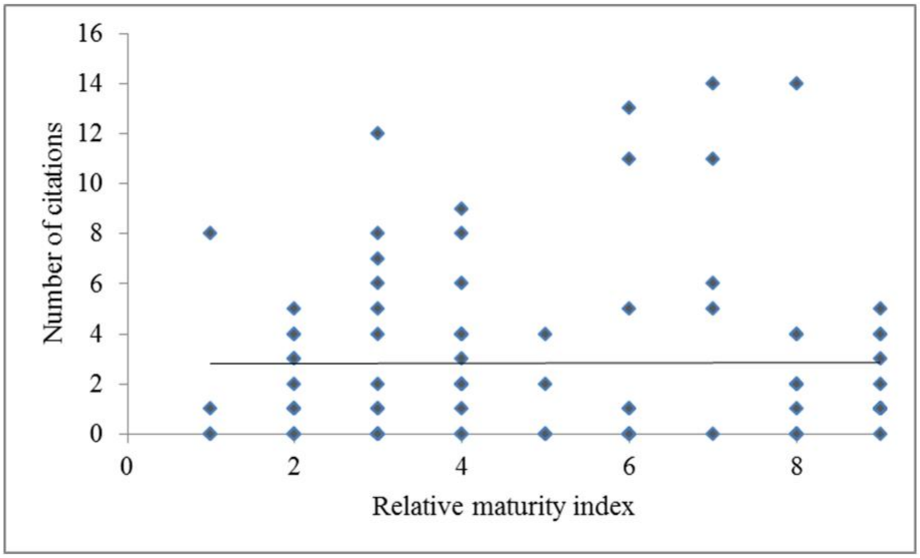
The most important limitation of our tests is that, although we use data on yields as the bottom line measure of most characteristics and include moisture as an additional control, we cannot control for all characteristics of hybrid corn. Most of these characteristics, such as resistance to herbicides or pests, affect the quality of hybrid corn through improvements in yields, but one important adaptive characteristics – variation in the suitability to different climates – cannot be captured by measuring yields.[35] New hybrids may have been developed to take advantage of climatic conditions in different locations of North America; regions with colder climates and shorter summers require hybrids with earlier relative maturity rates (i.e., fewer days required to grow.)

To examine whether such variation might explain relatively low rates of improvement measured by raw patent counts, or perhaps even the strong positive correlation between yields and citations, we collect data on variation in relative levels of maturity for Pioneer hybrids, whose names include encoded information on relative maturity. Specifically, the second digit in the product names of new Pioneer hybrids between 1997 and 2005 identifies the relative maturity level on a scale from 0 (very full) to 9 (very short).[36] For example, the digit 9 preceding the "r" in the name of Pioneer's new hybrid 39r34 (USPTO 6,797,868; granted on September 28, 2004) indicates that this hybrid has a very short relative maturity. 89 of 215 total hybrids between 1997 and 2005 are Pioneer hybrids

[35] Variation in the sugar content of hybrids is another important characteristic that is not captured by variation in yields; to avoid this problem, we focus on a) field corn rather than sweet corn and b) on patent grants that precede the Energy Act of 2005, which increased the relative price of ethanol and motivated breeders of field corn to shift towards improving hybrids to produce more sugar (and thereby ethanol).

[36] See www.pioneer.com/home/site/ca/products/product-naming-system for a key to Pioneer's naming practices.

Figure 2.13: Relative Maturity of new Pioneer Hybrids versus Number of Citations



Notes: Starting in 1997, Pioneer reveals the relative maturity of newly patented hybrids through the product code that they assign to their new hybrids (details on the assignment of product name available at www.pioneer.com/home/site/ca/products/product-naming-system). The second digit reveals the relative maturity level with a larger number implying a shorter relative maturity. Data on all 89 patents with information on the relative maturity index in subclass 800/320.1 Maize granted between January 1, 1985 and March 8, 2005 assigned to Pioneer (available at www.uspto.gov).

and we are able to measure relative maturity for 89 hybrids of these hybrids.

Data on variation in the relative maturity of Pioneer hybrids yield no evidence of systematic changes in the number of citations (Figure 2.13). The correlation coefficient between the relative maturity level and the number of citations is 0.0011.[37]

[37]Including fixed effects to control for variation in relative maturity reduces the sample to 79 patents by Pioneer. In this subsample the p-value for the coefficient estimate of the average marginal effect of the percentage increase in yield per acre is 0.158 without maturity fixed effects and 0.197 with maturity fixed effects.

2.6 Conclusions

Our analysis of 256 utility patents for hybrid corn granted between 1986 and 2005 suggests that more than half of all newly patented hybrids do not produce more corn or income than existing hybrids. The data also indicate that improvements in yields per acre and in income are declining over time, possibly due to decreasing returns to invention.

Importantly, however, we establish a strong and robust positive relationship between the magnitude of inventions and the number of citations received from subsequently granted U.S. patents, suggesting that citations-adjusted patent counts are a useful measure for the magnitude of inventions.

Our analysis points out some of the shortcomings of alternative measures of patent quality. Breeders appear to develop templates for their claims and expand their templates to add new claims over time. Further, we find that renewal decisions for the patents in our data are independent the size of the improvements of the covered hybrids.

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CHAPTER 3

ON THE OPTIMALITY OF AWARDING PATENTS AND PRIZES AS INCENTIVES FOR INNOVATION

3.1 Introduction

There are various mechanisms intended to provide incentives for innovation. Two possible policy instruments are patents and prizes. The patent system grants exclusive rights to innovators for some period of time and prevents competitors from copying the innovation during the time period that the patent is in force. The benefit of granting monopoly rights, which induce innovation by allowing inventors to recoup the costs of an innovation, comes at the cost of the usual deadweight social loss due to the monopoly in the product market. There exists an extensive literature on the design of the patent system. Nordhaus (1969) is the seminal work with respect to the length of patent protection. Klemperer (1990), Gilbert and Shapiro (1990) and Gallini (1992) analyze the optimal design of patent protection if it is possible to choose both patent length as well as patent breadth. The case of sequential innovations was first considered by Scotchmer (1991), Green and Scotchmer (1995) and O'Donoghue et al. (1998).

Scotchmer (1999) introduces the idea that the current patent renewal system can be analyzed in a principal-agent model in which the patent office (principal) does not observe the type of the inventor (size of the invention) and offers a menu of patent length and associated fees. Analyzing the optimality of such a menu of patent length and associated fees, she finds that such a renewal system is only optimal under restrictive assumptions about the join distribution of patent value and R&D cost.

An alternative to patents are prizes. Prizes reward innovators while making the innovation available to the public immediately and therefore avoid the deadweight social loss of patents. However, in order to award optimal prizes, information about the social value of an innovation is required. Kremer (1998) and Chari et al. (2011) provide examples of how information available from other firms in the market can be used to learn about the social value of an innovation.

In this chapter, I derive optimal mechanisms of awarding patents and prizes under three different information environments. Using the full information environment as the benchmark, I analyze the case in which information about the value of an innovation is (i) only observed by the innovating firm or (ii) by the innovating firm and other firms in the same industry.

In general, the social planner awards prizes whenever these are available as a policy instrument. While there exist mechanisms to reveal the social value of an innovation under the private information environment, truth telling can only be achieved by providing some patent protection in most of the considered cases. The social surplus is then lower than the full information benchmark. When the social planner can use market information from competitors about the social value of an innovation, it is possible to achieve the same level of social surplus as in the full information benchmark.

3.2 Setup of the model

The basic setup follows what Scotchmer (2004) terms the "ideas model."[1] A firm (also referred to as the inventor) receives an idea. An idea is fully described by its value (or size) $v > 0$ and cost $c > 0$, jointly referred to as the inventor's type $\theta = (c, v)$, which is an element of the type space Θ. I assume that there are only two possible types

$$\theta \in \Theta = \left\{\theta^1, \theta^2\right\} = \left\{\left(c^1, v^1\right), \left(c^2, v^2\right)\right\}.$$

Without loss of generality, let $v^2 > v^1$. Let $p\left(v^1\right)$ denote the probability that the idea is of type θ^1 and $1 - p\left(v^1\right)$ denote the probability that the idea is of type θ^2. In order to turn an idea into an innovation, the firm must incur the one time cost c. A larger cost is associated with a larger value, so $c^2 > c^1 \Leftrightarrow v^2 > v^1$. Let $\pi\left(v\right)$ denote the per-period change in the inventor's profit that a patent would earn from an innovation of value v. I assume that $\pi\left(\cdot\right) > 0$ for all v and $v^2 > v^1 \Leftrightarrow \pi\left(v^2\right) > \pi\left(v^1\right)$. Associated with each innovation is a change in social surplus. Let $S^p\left(v\right)$ denote the per-period change in social surplus from an innovation of value v while the patent is in force and $S\left(v\right)$ denote the per-period change in social surplus while the patent is (no longer) in force.

Due to product market distortion, the per-period change in social surplus is smaller while a patent is in force. The per-period change in social surplus while the patent is in force consists of the producer and consumer surplus. Combining these two arguments gives $S\left(v\right) > S^p\left(v\right) > \pi\left(v\right)$ for an innovation of value v. I will assume that each innovation is socially desirable ($\frac{S(v)}{r} \geq c \quad \forall \left(c, v\right) = \theta \in \Theta$, where r denotes the interest rate used for discounting) and furthermore that

[1] Applications of the ideas model can be found for example in Green and Scotchmer (1995), O'Donoghue et al. (1998), Scotchmer (1999), Scotchmer (2004) and Chari et al. (2011).

(possibly infinite) patent protection would be sufficient to cover the cost of each innovation ($\frac{\pi(v)}{r} \geq c \quad \forall (c, v) = \theta \in \Theta$).

Assume that the social planner has two instruments to reward innovations at her disposal: patents and prizes. Patents represent an exclusive right to use the idea and are awarded for a certain duration of time. Let the discounted patent length be denoted by t , namely

$$t = \int_{0}^{\bar{t}} e^{-r\tau} d\tau = \frac{1}{r}\left(1 - e^{-r\bar{t}}\right)$$

where $\bar{t}$ denotes undiscounted length of time. The option to award patents includes the possibility to offer a menu of patent lengths and associated fees, which is equivalent to a system of patent renewal. Therefore t might depend on v and I denote the (discounted) patent length as $t\,(v)$. Let $x\,(v)$ denote the fee associated with a patent of (discounted) length $t\,(v)$.

The second instrument available to the social planner are prizes (denoted by $P\,(v)$), which are lump sum transfers financed by lump sum taxes on consumers. However, I impose an upper bound equal to the maximum discounted change in social surplus associated with an innovation, that is $P\,(v) \leq \frac{S(v)}{r}$. For the case that both a patent and a prize are awarded simultaneously, I impose the restriction that $\pi\,(v)\,t\,(v) - x\,(v) + P\,(v) \leq \frac{S(v)}{r}$.

Notice that a patent on its own can never 'over-reward' an innovation. The longest possible patent protection is a patent of infinite (undiscounted) duration or equivalently $t = \frac{1}{r}$. From $\pi\,(v) < S\,(v)$, it follows that $\frac{\pi(v)}{r} < \frac{S(v)}{r}$.

The objective of the social planner is to maximize social surplus. The objective function is given by

$$p\left(v^1\right)\left[S^p\left(v^1\right)t\left(v^1\right)+S\left(v^1\right)\left(\frac{1}{r}-t\left(v^1\right)\right)\right]$$
$$+\left(1-p\left(v^1\right)\right)\left[S^p\left(v^2\right)t\left(v^2\right)+S\left(v^2\right)\left(\frac{1}{r}-t\left(v^2\right)\right)\right].$$

In the objective function, the change in social surplus is equal to $S^p(v)$ while the patent is in force during the time period between 0 and $\bar{t}(v)$ (or equivalently in discounted time: $t(v)$). From $\bar{t}(v)$ onwards, the patent is no longer in force and the the change in social surplus is equal to $S(v)$. Transfers to or from the innovator are lump sum transfers and therefore not costly or beneficial from a social point of view.

3.3 Full information

The cost and value of the idea are fully observed by the innovator and the social planner.

3.3.1 Patents

Suppose that only patents are available as a policy instrument.[2] In this case it is optimal to award patents of length $t(v^1)=t^1=\frac{c^1}{\pi(v^1)}$ and $t(v^2)=t^2=\frac{c^2}{\pi(v^2)}$. Both types of patents will be granted without charging a fee, so $x(v^1)=x(v^2)=0$. An innovator of type θ^1 (or θ^2, respectively) will not invest in the idea if the patent length is shorter than t^1 (or t^2, respectively), since she would not be able to cover the cost c^1 (or c^2, respectively). Since both types of innovations are

[2] A similar analysis of the full information case when only patents are available as a reward can be found in chapter 4 of Scotchmer (2004).

assumed to be socially beneficial ($\frac{S(v)}{r} \geq c$), a patent length shorter than t^1 (or t^2, respectively) cannot be socially optimal. Since $S^p(v) < S(v)$, any patent length longer than t^1 (or t^2, respectively) would decrease social surplus. While it would be possible to 'tax' any profit above what is necessary to cover the cost of the innovation through charging fees (turning producer into consumer surplus), some social surplus would be lost (to be precise: $S(v) - S^P(v)$ for every increase in $t(v)$). Therefore, a patent length longer than t^1 (or t^2, respectively) cannot be socially optimal.

3.3.2 Patents and prizes

Suppose now that prizes are available in addition to patents. In this case, it is optimal to use prizes exclusively. Since both types of innovations are assumed to be socially beneficial ($\frac{S(v)}{r} \geq c$), the planner should provide enough incentives to the innovator of both types to invest in the idea. Since prizes do not affect the social surplus, setting them to $c^1 \leq P(v^1) \leq \frac{S(v^1)}{r}$ and $c^2 \leq P(v^2) \leq \frac{S(v^2)}{r}$ allows the inventor to recover the cost and maximizes social surplus.[3] Since $S^p(v) < S(v)$, any positive patent length would decrease social surplus.

3.4 Private information

This section considers the case that the cost and value of the idea are only observed by the innovator. The social planner does not observe the innovator's type , but has knowledge about the probability distribution over the type space.

[3]Notice that a prize of $P(v) = c$ would maximize consumer surplus and a prize of $P(v) = \frac{S(v)}{r}$ would maximize producer surplus.

3.4.1 Patents

Suppose that only patents are available as a policy instrument.[4] There are three different possible relationships between the cost and per-period change in profit associated with an innovation:

1. If $\frac{c^1}{\pi(v^1)} = \frac{c^2}{\pi(v^2)}$, the social planner should award patents of discounted length $t^1 = \frac{c^1}{\pi(v^1)} = \frac{c^2}{\pi(v^2)} = t^2$ and charge no fees. An innovator of type θ^1 (or θ^2, respectively) will not invest in the idea if the patent length is shorter than t^1 (or t^2, respectively), since she would not be able to cover the cost c^1 (or c^2, respectively). Since both types of innovations are assumed to be socially beneficial, a patent length shorter than t^1 (or t^2, respectively) cannot be socially optimal. Any patent length longer than t^1 (or t^2, respectively) would decrease social surplus. Charging fees would require an increase in patent length to prevent the innovator from dropping the innovation. The increase in patent length would decrease social surplus, while the fees would not increase social surplus. Therefore, the social planner should not charge any fees. The outcome in terms of social surplus is identical to the full information case above.

2. If $\frac{c^1}{\pi(v^1)} < \frac{c^2}{\pi(v^2)}$, the social planner can implement a menu of patent lengths and associated fees . The intuition behind the menu of patent lengths and associated fees is the following: the cost structure implies that the innovator of type θ^2 requires a longer patent protection to cover her cost than the innovator of type θ^1. Since patent protection should be kept as short as possible (in the sense that it needs to be long enough to induce invest-

[4] A similar analysis of the private information case in which patents are available as a reward can be found in Scotchmer (1999).

ment into the idea) to maximize social welfare, the social planner can use a direct revelation mechanism to learn about the type of the innovator and award a patent with a duration depending on the reported type. Charging a higher fee for a longer patent makes it possible that the incentive constraints hold. Notice that an increase in the patent duration is more beneficial to the innovator of type θ^2, since the increase in the per-period profit is larger for the type θ^2 ($\pi(v^2) > \pi(v^1)$). Therefore, the type θ^2 is willing to pay a higher fee for an increase in the duration of patent protection compared to an innovator of type θ^1. Increasing the patent length above the level that would be required to just cover the cost for the type θ^2 and simultaneously increasing the associated fee such that the innovator of type θ^2 can just cover her cost, makes the longer patent less and less attractive to the innovator of type θ^1, up to the point where the type θ^1 innovator prefers the shorter patent. However, the longest patent that can be awarded is a patent of infinite length (in undiscounted time) or equivalently of $t = \frac{1}{r}$ (in discounted time). The setup of the model allows for the case that a type θ^2 idea requires an infinite patent length (in undiscounted time). In addition to the situations in which the required minimum patent length is at or close to the upper bound, the larger the difference between the minimum patent lengths ($\frac{c^2}{\pi(v^2)} - \frac{c^1}{\pi(v^1)}$), the larger will be the required increase in the patent length for the type θ^2 innovator. Therefore, there will be cases in which it is not possible to construct such a menu of patent lengths and associated fees. In what follows, I will distinguish between both scenarios and show in which cases it is actually optimal to implement the direct revelation mechanism.

(a) Assume that $\frac{c^2-c^1}{\pi(v^2)-\pi(v^1)} \leq \frac{1}{r}$. I will show below that the left-hand side of this condition is the patent length necessary to induce truth telling. The right-hand side is the upper limit of patent protection in discounted time (equivalent to infinite patent protection in undiscounted time). If this condition fails, it is not possible to construct such a menu of patent lengths and associated fees.

The participation constraints are given by

$$\pi\left(v^{1}\right)t\left(v^{1}\right)-c^{1}-x\left(v^{1}\right)\geq 0$$

and

$$\pi\left(v^{2}\right)t\left(v^{2}\right)-c^{2}-x\left(v^{2}\right)\geq 0.$$

The incentive constraints are given by

$$\pi\left(v^{1}\right)t\left(v^{1}\right)-c^{1}-x\left(v^{1}\right)\geq \pi\left(v^{1}\right)t\left(v^{2}\right)-c^{1}-x\left(v^{2}\right)$$

and

$$\pi\left(v^{2}\right)t\left(v^{2}\right)-c^{2}-x\left(v^{2}\right)\geq \pi\left(v^{2}\right)t\left(v^{1}\right)-c^{2}-x\left(v^{1}\right).$$

It is no longer possible to award patents of length $t\left(v^{1}\right)=\frac{c^{1}}{\pi\left(v^{1}\right)}$ and $t\left(v^{2}\right)=\frac{c^{2}}{\pi\left(v^{2}\right)}$ with associated fees being equal to $x\left(v^{1}\right)=x\left(v^{2}\right)=0$. The inventor of type θ^{1} would claim to be of type θ^{2} in order to be awarded the longer patent protection. In order to decide whether to implement the direct revelation mechanism or not, the planner has to evaluate the benefit of having a shorter patent length for the innovator of type θ^{1} ($\frac{c^{1}}{\pi(v^{1})}$ versus $\frac{c^{2}}{\pi(v^{2})}$) with the cost of a longer patent length for the innovator of type θ^{2} ($\frac{c^{2}-c^{1}}{\pi(v^{2})-\pi(v^{1})}$ versus $\frac{c^{2}}{\pi(v^{2})}$), weighted by their respective probabilities.

i. Assume that $p\left(v^{1}\right)\left[S\left(v^{1}\right)-S^{p}\left(v^{1}\right)\right]\left[\frac{c^{2}}{\pi(v^{2})}-\frac{c^{1}}{\pi(v^{1})}\right]$ $\geq \left(1-p\left(v^{1}\right)\right)\left[S\left(v^{2}\right)-S^{p}\left(v^{2}\right)\right]\left[\frac{c^{2}-c^{1}}{\pi(v^{2})-\pi(v^{1})}-\frac{c^{2}}{\pi(v^{2})}\right]$. The social planner should offer a patent of length $t\left(v^1\right)=\frac{c^1}{\pi(v^1)}$ at no charge (so $x\left(v^1\right)=0$) and a patent of length $t\left(v^2\right)=\frac{c^2-c^1}{\pi(v^2)-\pi(v^1)}$ for a fee of $x\left(v^2\right)=\frac{c^2\pi\left(v^1\right)-c^1\pi\left(v^2\right)}{\pi(v^2)-\pi(v^1)}$.

To derive $t\left(v^2\right)$ and $x\left(v^2\right)$, we need to consider the participation constraint of the innovator of type θ^2 and the incentive constraint of the innovator of type θ^1. Solving the participation constraint for $x\left(v^2\right)$ gives

$$x\left(v^2\right)=\pi\left(v^2\right)t\left(v^2\right)-c^2.$$

Given $t\left(v^1\right)=\frac{c^1}{\pi(v^1)}$ and $x\left(v^1\right)=0$, solving the incentive constraint of the innovator of type θ^1 for $x\left(v^2\right)$ gives

$$x\left(v^2\right)=\pi\left(v^1\right)t\left(v^2\right)-c^1.$$

Setting both equations equal gives the patent length

$$t\left(v^2\right)=\frac{c^2-c^1}{\pi\left(v^2\right)-\pi\left(v^1\right)}$$

and the associated fee

$$x\left(v^2\right)=\pi\left(v^1\right)\frac{c^2-c^1}{\pi\left(v^2\right)-\pi\left(v^1\right)}-c^1=\frac{c^2\pi\left(v^1\right)-c^1\pi\left(v^2\right)}{\pi\left(v^2\right)-\pi\left(v^1\right)}.$$

ii. Assume that $p\left(v^1\right)\left[S\left(v^1\right)-S^p\left(v^1\right)\right]\left[\frac{c^2}{\pi(v^2)}-\frac{c^1}{\pi(v^1)}\right]$ $<\left(1-p\left(v^1\right)\right)\left[S\left(v^2\right)-S^p\left(v^2\right)\right]\left[\frac{c^2-c^1}{\pi(v^2)-\pi(v^1)}-\frac{c^2}{\pi(v^2)}\right]$. Although it is possible, it is not optimal to implement a menu of patent lengths and associated fees. The social planner should offer a patent of fixed length $t=\frac{c^2}{\pi(v^2)}$. Notice that it will never be optimal to just induce the innovation of type θ^1 by offering a fixed patent length of $t\left(v^1\right)=\frac{c^1}{\pi(v^1)}$ only. Offering a menu of patent lengths and associated fees would lead to an increase in social surplus even if $t\left(v^2\right)=\frac{1}{r}$, since $\frac{S^p\left(v^2\right)}{r}\geq c^2$

(b) Assume that $\frac{c^2 - c^1}{\pi(v^2) - \pi(v^1)} > \frac{1}{r}$. It is no longer possible to induce truth telling through implementing a menu of patent lengths and associated fees, since even a patent of discounted duration $1/r$ (or equivalently of infinite undiscounted duration) would not be sufficient to compensate the fee that the type θ^2 innovator has to pay in order to prevent the type θ^1 innovator from pretending to be of type θ^2. In this case, the social planner should either offer a patent of fixed length $t = \frac{c^1}{\pi(v^1)}$ and only the type θ^1 innovator will invest into her idea or offer a patent of fixed length $t = \frac{c^2}{\pi(v^2)}$ in which case both types of innovators would invest. Which of these options is optimal depends on the benefit that stems from having a shorter patent protection for the type θ^1 versus the cost of not realizing the innovation of type θ^2 at all, weighted by their respective probabilities.

i. If $p\left(v^1\right)\left[S\left(v^1\right) - S^p\left(v^1\right)\right]\left[\frac{c^2}{\pi(v^2)} - \frac{c^1}{\pi(v^1)}\right]$ $\leq \left(1 - p\left(v^1\right)\right)\left[S^p\left(v^2\right)\frac{c^2}{\pi(v^2)} + S\left(v^2\right)\left(\frac{1}{r} - \frac{c^2}{\pi(v^2)}\right)\right]$, the social planner should award a patent of length $t = \frac{c^2}{\pi(v^2)}$ to both types of innovators. Both types of innovators will invest. The innovator of type θ^2 will be able to just cover her cost, while the innovator of type θ^1 will generate discounted profits strictly above c^1, but below $\frac{S(v^1)}{r}$.

ii. If $p\left(v^1\right)\left[S\left(v^1\right) - S^p\left(v^1\right)\right]\left[\frac{c^2}{\pi(v^2)} - \frac{c^1}{\pi(v^1)}\right]$ $> \left(1 - p\left(v^1\right)\right)\left[S^p\left(v^2\right)\frac{c^2}{\pi(v^2)} + S\left(v^2\right)\left(\frac{1}{r} - \frac{c^2}{\pi(v^2)}\right)\right]$, the planner should offer a patent of length $t = \frac{c^1}{\pi(v^1)}$. Only the innovator of type θ^1 will accept. The innovator of type θ^2 will choose not to invest into the idea. Awarding a patent of length $t = \frac{c^2}{\pi(v^2)}$ would be socially wasteful, since the additional benefit of inducing an innovator of type θ^2 to invest into her idea would not outweigh the loss in social surplus due to the extended patent protection for the type θ^1 innovation. The optimal patent length cannot be longer than $t = \frac{c^1}{\pi(v^1)}$. An innovator of type θ^1 would not invest into her idea if a patent of length shorter than $t = \frac{c^1}{\pi(v^1)}$ is awarded. Therefore awarding a patent of length $t = \frac{c^1}{\pi(v^1)}$ is optimal.

3. If $\frac{c^1}{\pi(v^1)} > \frac{c^2}{\pi(v^2)}$, it is no longer possible to offer a menu of patent lengths and associated fees to induce truth telling. To see why a menu of fees and patent lengths is no longer feasible, consider the incentive constraints

$$\pi\left(v^1\right)t\left(v^1\right) - c^1 - x\left(v^1\right) \geq \pi\left(v^1\right)t\left(\theta^2\right) - c^1 - x\left(v^2\right)$$

or

$$\pi\left(v^1\right)\left[t\left(v^1\right) - t\left(v^2\right)\right] \geq x\left(v^1\right) - x\left(v^2\right)$$

and

$$\pi\left(v^2\right)t\left(v^2\right) - c^2 - x\left(v^2\right) \geq \pi\left(v^2\right)t\left(v^1\right) - c^2 - x\left(v^1\right)$$

or

$$\pi\left(v^2\right)\left[t\left(v^1\right) - t\left(v^2\right)\right] \leq x\left(v^1\right) - x\left(v^2\right).$$

Combining them gives

$$\pi\left(v^2\right)\left[t\left(v^1\right) - t\left(v^2\right)\right] \leq x\left(v^1\right) - x\left(v^2\right) \leq \pi\left(v^1\right)\left[t\left(v^1\right) - t\left(v^2\right)\right].$$

Since

$$c^1/\pi_i\left(v^1\right) > c^2/\pi_i\left(v^2\right),$$

the type θ^1 innovation requires a longer patent length. If patent lengths are differentiated in the optimum, then it must be that patent protection is longer for the type θ^1 innovator ($t(v^1) - t(v^2) > 0$). But since $\pi(v^2) > \pi(v^1)$ it is impossible to have

$$\pi\left(v^2\right)\left[t\left(\theta^1\right) - t\left(\theta^2\right)\right] \leq \pi\left(v^1\right)\left[t\left(\theta^1\right) - t\left(\theta^2\right)\right].$$

Therefore, the social planner should offer a patent of fixed duration at no charge. The patent length should be fixed at either $t = \frac{c^2}{\pi(v^2)}$ and only the type θ^2 innovator will invest or $t = \frac{c^1}{\pi(v^1)}$ in which case both types of innovators would invest. Which of these options is optimal depends on the benefit that stems from having a shorter patent protection for the type θ^2 versus the cost of not realizing the innovation of type θ^1 at all, weighted by their respective probabilities.

(a) If $p(v^1)\left[S^p(v^1)\frac{c^1}{\pi(v^1)} + S(v^1)\left(\frac{1}{r} - \frac{c^1}{\pi(v^1)}\right)\right]$ $\geq (1 - p(v^1))\left[S(v^2) - S^p(v^2)\right]\left[\frac{c^1}{\pi(v^1)} - \frac{c^2}{\pi(v^2)}\right]$, the social planner should award a patent of length $t = \frac{c^1}{\pi(v^1)}$ to both types of innovators. Both types of innovators will invest. The innovator of type θ^1 will be able to just cover her cost, while the innovator of type θ^2 will generate discounted profits strictly above c^2, but below $\frac{S(v^2)}{r}$.

(b) If $p(v^1)\left[S^p(v^1)\frac{c^1}{\pi(v^1)} + S(v^1)\left(\frac{1}{r} - \frac{c^1}{\pi(v^1)}\right)\right]$ $< (1 - p(v^1))\left[S(v^2) - S^p(v^2)\right]\left[\frac{c^1}{\pi(v^1)} - \frac{c^2}{\pi(v^2)}\right]$, the planner should offer a patent of length $t = \frac{c^2}{\pi(v^2)}$. Only the innovator of type θ^2 will accept. The innovator of type θ^1 will choose not to invest into the idea. Awarding a patent of length $t = \frac{c^1}{\pi(v^1)}$ would be socially wasteful, since the additional benefit of inducing an innovator of type θ^1 would not outweigh the loss in social surplus due to the extended patent protection for the type θ^2 innovation. The optimal patent length cannot be longer than $t = \frac{c^2}{\pi(v^2)}$. An innovator of type θ^2 would not invest into her idea if a patent of length shorter than $t = \frac{c^2}{\pi(v^2)}$ is awarded. Therefore awarding a patent of length $t = \frac{c^2}{\pi(v^2)}$ is optimal.

3.4.2 Patents and prizes

Suppose now that prizes are available in addition to patents.

1. Assume that $\frac{S(v^1)}{r} \geq c^2$. In this case the social planner should award prizes exclusively in order to maximize social surplus. The prize should be $c^2 \leq P(\cdot) \leq \frac{S(v^1)}{r}$. Since $c^2 > c^1$ both types of innovators would invest in their socially desirable ideas. Since $\frac{S(v^2)}{r} > \frac{S(v^1)}{r}$ the upper bound condition would also hold for the innovator of type θ^2. Since prizes are financed through lump sum taxes, they do not affect social surplus.

2. Assume that $\frac{S(v^1)}{r} < c^2$. It is optimal for the social planner to randomize the awarding of a patent or a prize. Let $q(v)$ denote the probability that the social planner awards a patent and $(1 - q(v))$ denote the probability that the planner awards a prize. It is possible to induce truth telling by randomizing over awarding a patent of length $t(v^1) = \frac{c^1}{\pi(v^1)}$ and $t(v^2) = \frac{c^2}{\pi(v^2)}$, respectively, and awarding a prize of $P(v^1) = \frac{S(v^1)}{r}$ and $P(v^2) = \frac{S(v^2)}{r}$, respectively.

   The participation constraints are given by

   $$q\left(v^1\right)\pi\left(v^1\right)\frac{c^1}{\pi(v^1)} - c^1 + \left(1 - q\left(v^1\right)\right)\frac{S(v^1)}{r} \geq 0$$

   $$q\left(v^2\right)\pi\left(v^2\right)\frac{c^2}{\pi(v^2)} - c^2 + \left(1 - q\left(v^2\right)\right)\frac{S(v^2)}{r} \geq 0.$$

   Notice that the participation constraints will always hold. The incentive constraints are given by

$$q\left(v^1\right)\pi\left(v^1\right)\frac{c^1}{\pi\left(v^1\right)}-c^1+\left(1-q\left(v^1\right)\right)\frac{S\left(v^1\right)}{r}$$
$$\geq q\left(v^2\right)\pi\left(v^1\right)\frac{c^2}{\pi\left(v^2\right)}-c^1+\left(1-q\left(v^2\right)\right)\frac{S\left(v^2\right)}{r}$$

$$q\left(v^2\right)\pi\left(v^2\right)\frac{c^2}{\pi\left(v^2\right)}-c^2+\left(1-q\left(v^2\right)\right)\frac{S\left(v^2\right)}{r}$$
$$\geq q\left(v^1\right)\pi\left(v^2\right)\frac{c^1}{\pi\left(v^1\right)}-c^2+\left(1-q\left(v^1\right)\right)\frac{S\left(v^1\right)}{r}.$$

Solving for the incentive constraints for $q\left(v^2\right)$ gives

$$q\left(v^2\right)\geq\frac{q\left(v^1\right)\left[\frac{S\left(v^1\right)}{r}-c^1\right]+\frac{S\left(v^2\right)}{r}-\frac{S\left(v^1\right)}{r}}{\frac{S\left(v^2\right)}{r}-\frac{\pi\left(v^1\right)}{\pi\left(v^2\right)}c^2}$$

$$q\left(v^2\right)\leq\frac{q\left(v^1\right)\left[\frac{S\left(v^1\right)}{r}-\frac{\pi\left(v^2\right)}{\pi\left(v^1\right)}c^1\right]+\frac{S\left(v^2\right)}{r}-\frac{S\left(v^1\right)}{r}}{\frac{S\left(v^2\right)}{r}-c^2}.$$

The planner can set $q\left(v^1\right)=0$ (that is: award a prize with probability one to the type θ^1). Since $\pi\left(v^1\right)<\pi\left(v^2\right)$, $\frac{S\left(v^2\right)}{r}-\frac{\pi\left(v^1\right)}{\pi\left(v^2\right)}c^2>\frac{S\left(v^2\right)}{r}-c^2$ and there exists a $q\left(v^2\right)$ such that both inequalities hold. Since $\frac{c^2}{\pi\left(v^2\right)}\leq\frac{1}{r}$ and $\pi\left(v^1\right)<S\left(v^1\right)$, the lower bound will be smaller than 1. In order to maximize social surplus, the planner should pick the lowest $q\left(v^2\right)$ feasible (that is the largest feasible probability of awarding a prize). This is given by the lower bound, so

$$q\left(v^2\right)=\frac{\frac{S\left(v^2\right)}{r}-\frac{S\left(v^1\right)}{r}}{\frac{S\left(v^2\right)}{r}-\frac{\pi\left(v^1\right)}{\pi\left(v^2\right)}c^2}.$$

3.5 Market information

The cost and value of the idea are not observed by the social planner. However, an additional firm (also referred to as the competitor) receives information

s equal to the value of the idea, so $s = v$. Let $\pi^c(v)$ denote the per-period change in the competitor's profit from an innovation of value v while a patent protecting this innovation is in force. I assume that $\pi^c(\cdot) < 0$ for all v and $v^2 > v^1 \Leftrightarrow \pi^c(v^2) < \pi^c(v^1)$. The competitor (truthfully or untruthfully) reports the information she received to the social planner. The patent length, the associated fee and the prize may all depend on the reported type of the innovator as well as the reported information of the competitor: $t(v,s)$, $x(v,s)$ and $P(v,s)$, respectively.

3.5.1 Patents

Suppose that only patents are available as a reward. There are three different possible relationships between the cost and per-period change in profit associated with an innovation:

1. If $\frac{c^1}{\pi(v^1)} = \frac{c^2}{\pi(v^2)}$, the social planner should award patents of discounted length $t^1 = \frac{c^1}{\pi(v^1)} = \frac{c^2}{\pi(v^2)} = t^2$ and charge no fees. The information from the competitor is irrelevant. An innovator of type θ^1 (or θ^2, respectively) will not invest in the idea if the patent length is shorter than t^1 (or t^2, respectively), since she would not be able to cover the cost c^1 (or c^2, respectively). Since both types of innovations are assumed to be socially beneficial, a patent length shorter than t^1 (or t^2, respectively) cannot be socially optimal. Any patent length longer than t^1 (or t^2, respectively) would decrease social surplus. Charging fees would require an increase in patent length to prevent the innovator from dropping the innovation. The increase in patent length would decrease social surplus, while the fees would not in-

crease social surplus. Therefore, the social planner should not charge any fees. The outcome in terms of social surplus is identical to the full information case above.

2. If $\frac{c^1}{\pi(v^1)} < \frac{c^2}{\pi(v^2)}$ or $\frac{c^1}{\pi(v^1)} > \frac{c^2}{\pi(v^2)}$, the social planner should award a patent of length $t(v,s) = \frac{c}{\pi(v)}$ if the reported type and the reported information are the same, so $t(v^1,v^1) = \frac{c^1}{\pi(v^1)}$ and $t(v^2,v^2) = \frac{c^2}{\pi(v^2)}$, and charge no fees, so $x(v^1,v^1) = 0$ and $x(v^2,v^2) = 0$. If the reported type and reported information are different, the social planner awards a patent of maximum duration to the innovator, so $t(v^1,v^2) = t(v^2,v^1) = \frac{1}{r}$, but charges fees of $x(v^1,v^2) = \pi(v^2)\left[\frac{1}{r} - \frac{c^2}{\pi(v^2)}\right]$ and $x(v^2,v^1) = \pi(v^1)\left[\frac{1}{r} - \frac{c^1}{\pi(v^1)}\right]$, respectively. The participation constraints for the innovator are given by

$$\pi\left(v^1\right) t\left(v^1,v^1\right) - c^1 - x\left(v^1,v^1\right) \geq 0$$

and

$$\pi\left(v^2\right) t\left(v^2,v^2\right) - c^2 - x\left(v^2,v^2\right) \geq 0.$$

Given the proposed patent lengths and fees above, the participation constraints become

$$\pi\left(v^1\right)\frac{c^1}{\pi\left(v^1\right)} - c^1 \geq 0$$

and

$$\pi\left(v^2\right)\frac{c^2}{\pi\left(v^2\right)} - c^2 \geq 0.$$

The incentive constraints are given by

$$\pi\left(v^1\right) t\left(v^1,v^1\right) - c^1 - x\left(v^1,v^1\right) \geq \pi\left(v^1\right) t\left(v^2,v^1\right) - c^1 - x\left(v^2,v^1\right)$$

and

$$\pi\left(v^2\right) t\left(v^2,v^2\right) - c^2 - x\left(v^2,v^2\right) \geq \pi\left(v^2\right) t\left(v^1,v^2\right) - c^2 - x\left(v^1,v^2\right).$$

Given the proposed patent lengths and fees above, the incentive constraints become

$$\pi\left(v^1\right)\frac{c^1}{\pi\left(v^1\right)}-c^1\geq\pi\left(v^1\right)\frac{1}{r}-c^1-\pi\left(v^1\right)\left[\frac{1}{r}-\frac{c^1}{\pi\left(v^1\right)}\right]$$

and

$$\pi\left(v^2\right)\frac{c^2}{\pi\left(v^2\right)}-c^2\geq\pi\left(v^2\right)\frac{1}{r}-c^2-\pi\left(v^2\right)\left[\frac{1}{r}-\frac{c^2}{\pi\left(v^2\right)}\right].$$

The social planner can induce the competitor to participate in the mechanism by awarding a patent of maximum length in the case that the competitor does not report to the social planner. The participation constraints for the competitor are given by

$$\pi^c\left(v^1\right)t\left(v^1,v^1\right)\geq\pi^c\left(v^1\right)\frac{1}{r}$$

and

$$\pi^c\left(v^2\right)t\left(v^2,v^2\right)\geq\pi^c\left(v^2\right)\frac{1}{r}.$$

Any patent length shorter than the maximum patent length is preferred by the competitor, so the participation constraints will always hold. The incentive constraints are given by

$$\pi^c\left(v^1\right)t\left(v^1,v^1\right)\geq\pi^c\left(v^1\right)t\left(v^1,v^2\right)$$

and

$$\pi^c\left(v^2\right)t\left(v^2,v^2\right)\geq\pi^c\left(v^2\right)t\left(v^2,v^1\right).$$

Given the proposed patent lengths above, the incentive constraints become

$$\pi^c\left(v^1\right)\frac{c^1}{\pi\left(v^1\right)}\geq\pi^c\left(v^1\right)\frac{1}{r}$$

and

$$\pi^c\left(v^2\right)\frac{c^2}{\pi\left(v^2\right)}\geq\pi^c\left(v^2\right)\frac{1}{r}.$$

The outcome in terms of social surplus is identical to the full information case above.

3.5.2 Patents and prizes

Suppose now that prizes are available in addition to patents. The social planner should award prizes of $c^1 \leq P\left(v^1\right) \leq \frac{S\left(v^1\right)}{r}$ and $c^2 \leq P\left(v^2\right) \leq \frac{S\left(v^2\right)}{r}$, respectively, based on the report from the competitor. Since the competitor is not affected by the size of the transfer to the innovator, she can report truthfully. Since $S^p\left(v\right) < S\left(v\right)$, any positive patent length would decrease social surplus. The outcome in terms of social surplus is identical to the full information case above.

3.6 Conclusions

In this chapter, I derived optimal mechanisms of awarding patents and prizes under three different information environments. Using the full information environment as the benchmark, I analyzed the case in which information about the value of an innovation is either only observed by the innovating firm or by the innovating firm and another firm in the same industry. In general, the social planner awards prizes whenever these are available as a policy instrument. While there exist mechanisms to reveal the social value of an innovation under the private information environment, truth telling can only be achieved by providing some patent protection in most of the considered cases. The social surplus is then lower than the full information benchmark. When market information about the social value of an innovation is available from a competitor, the social planner can achieve the same level of social surplus as in the full information benchmark.

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APPENDIX A

APPENDIX TO CHAPTER 1

Table A.1: Granted Patents and Patent Applications by Technology Field: SEC Sample

Technology field	Granted patents	Patent applications	Total
Chemicals (excl. Drugs)	**88**	**20**	**108**
Agriculture, Food, Textiles	0	1	1
Coating	3	0	3
Gas	2	0	2
Organic Compounds	32	11	42
Resins	8	2	10
Miscellaneous	43	6	49
Computers and Communication	**802**	**248**	**1,050**
Communications	272	69	341
Computer Hardware & Software	258	102	360
Computer Peripherals	87	27	114
Information Storage	149	21	170
Electronic business methods and software	36	29	65
Drugs and Medical	**137**	**146**	**283**
Drugs	105	87	192
Surgery & Med Inst.	21	45	66
Genetics	4	2	6
Miscellaneous	7	12	19
Electrical and Electronics	**383**	**110**	**493**
Electrical Devices	36	2	38
Electrical Lighting	29	0	29
Measuring & Testing	24	3	27
Nuclear & X-rays	46	6	52
Power Systems	16	4	20
Semiconductor Devices	152	47	199
Miscellaneous	80	48	128
Mechanical	**56**	**6**	**62**
Mat. Processing & Handling	8	2	10
Metal Working	11	1	12
Motors & Engines + Parts	0	0	0
Optics	12	0	12
Transportation	0	0	0
Miscellaneous	25	3	28
Other	**44**	**5**	**49**
Agriculture, Husbandry, Food	1	0	1
Amusement Devices	2	0	2
Apparel & Textile	0	0	0
Earth Working & Wells	0	0	0
Furniture, House Fixtures	9	1	10
Heating	1	0	1
Pipes & Joints	1	0	1
Receptacles	1	0	1
Miscellaneous	29	4	33
Total	**1,510**	**535**	**2,045**

Notes: Granted patents and patent applications as of date of trade. Technology field definitions based on **?**.

Table A.2: Granted Patents and Patent Applications by Technology Field: Random Sample

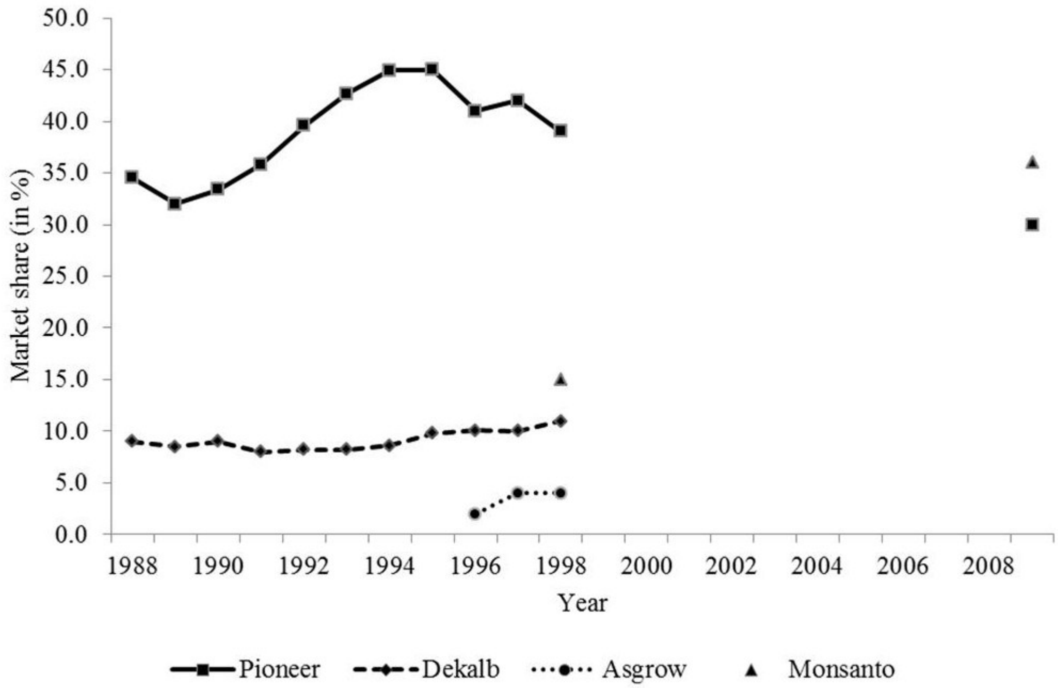
Technology field	Granted patents	Patent applications	Total
Chemicals (excl. Drugs)	**139**	**52**	**191**
Agriculture, Food, Textiles	1	0	1
Coating	15	2	17
Gas	1	2	3
Organic Compounds	12	7	19
Resins	18	10	28
Miscellaneous	92	31	123
Computers and Communication	**323**	**112**	**435**
Communications	155	52	207
Computer Hardware & Software	79	32	111
Computer Peripherals	25	7	32
Information Storage	34	7	41
Electronic business methods and software	30	14	44
Drugs and Medical	**195**	**58**	**253**
Drugs	78	24	102
Surgery & Med Inst.	93	22	115
Genetics	0	3	3
Miscellaneous	34	9	33
Electrical and Electronics	**375**	**65**	**440**
Electrical Devices	51	9	60
Electrical Lighting	22	1	23
Measuring & Testing	109	27	136
Nuclear & X-rays	107	5	112
Power Systems	18	4	22
Semiconductor Devices	46	7	53
Miscellaneous	22	12	34
Mechanical	**181**	**30**	**211**
Mat. Processing & Handling	43	3	46
Metal Working	31	9	40
Motors & Engines + Parts	23	2	25
Optics	45	9	54
Transportation	13	3	16
Miscellaneous	26	4	30
Other	**217**	**49**	**266**
Agriculture, Husbandry, Food	24	2	26
Amusement Devices	15	4	19
Apparel & Textile	8	1	9
Earth Working & Wells	7	3	10
Furniture, House Fixtures	14	0	14
Heating	20	0	20
Pipes & Joints	3	3	6
Receptacles	30	16	46
Miscellaneous	96	20	116
Total	**1,430**	**366**	**1,796**

Notes: Granted patents and patent applications as of date of trade. Technology field definitions based on **?**.

APPENDIX B

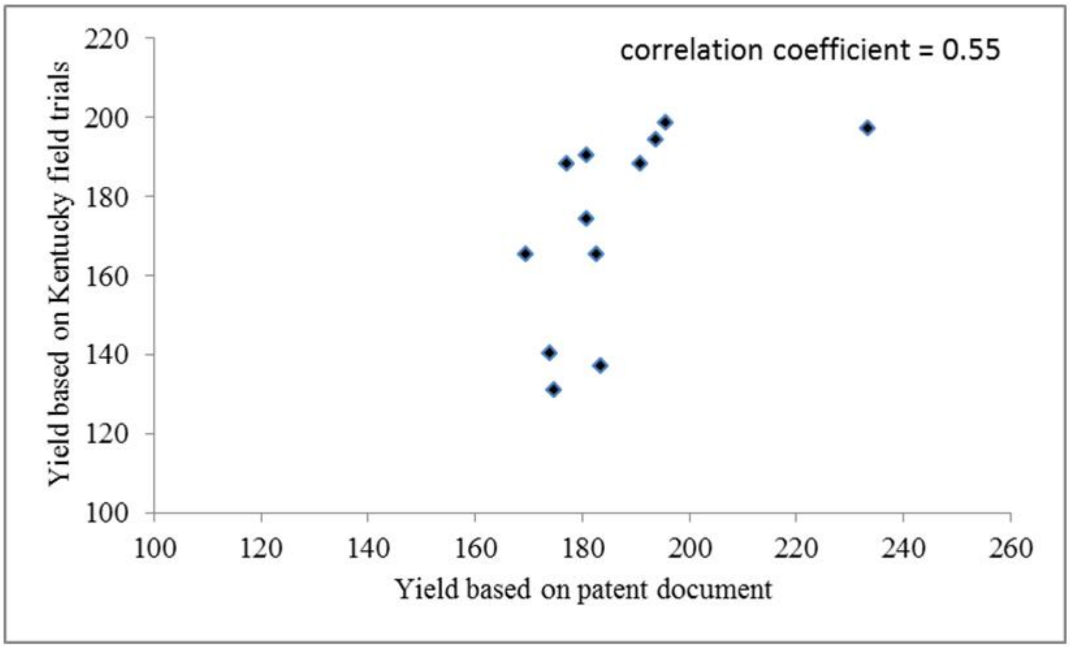
APPENDIX TO CHAPTER 2

Figure B.1: Market Share in the Corn Seed Industry



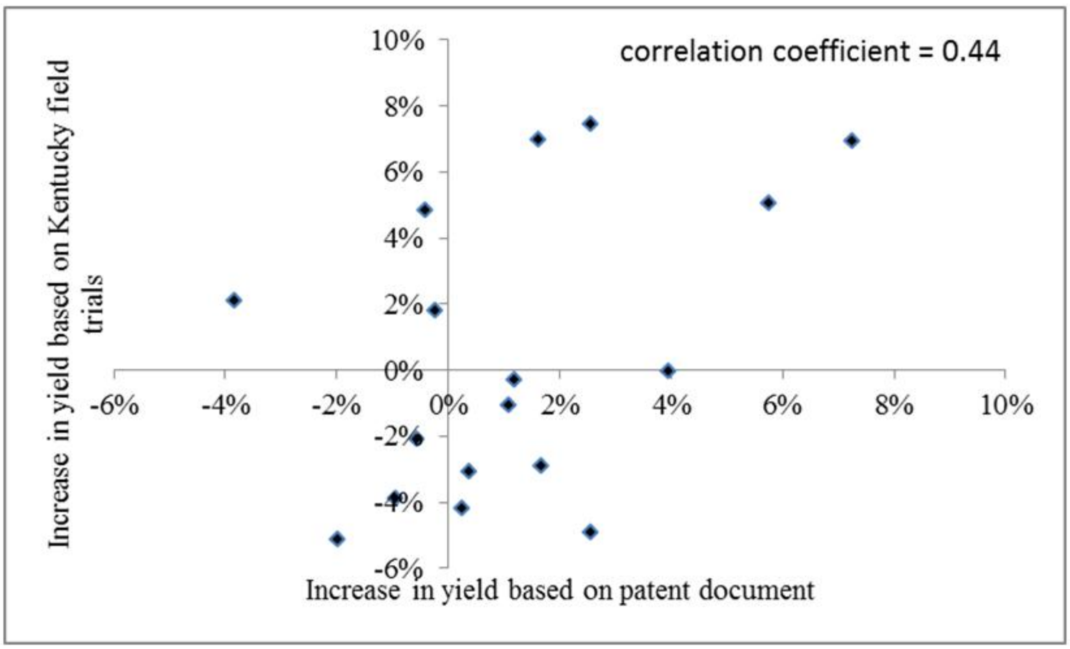
Notes: Data for the time period 1988 to 1998 from USDA Agriculture Information Bulletin #786. Data for 2009 are estimates from Deutsche Bank Research (as quoted in the Des Moines Register October 5, 2009). The 1998 data point for Monsanto is the combined market share of Dekalb and Asgrow. Dekalb was purchased by the Monsanto in 1998. Monsanto completed the acquisition of Asgrow in 1998.

Figure B.2: Comparison of absolute Yields reported in the Patents with absolute Yields from independent Field Trials



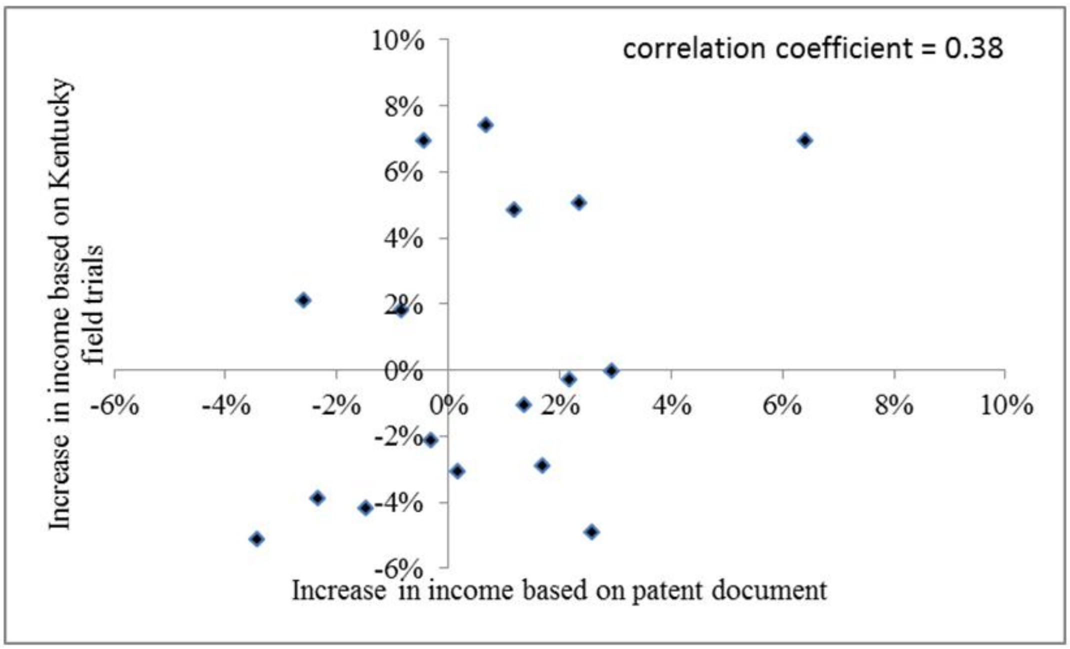
Notes: Each of the 12 data points represents a new hybrid for which we observe the absolute yield level in the patent document as well as in the Kentucky Performance Test reports. Since yield for the same hybrid vary from year to year, all absolute yield levels were normalized to 1998 yields level using data on the average yield in the U.S. Since we do not observe the information on the year in which the field trials were conducted for the data in the patent document, we use the year prior the year of application as the estimate. Data on yields were collected by a manual search of the full text of patent documents. Independent test station data from the University of Kentucky (http://www.uky.edu/Ag/GrainCrops/varietytesting.htm). Data on U.S. averages from the United States Department of Agriculture (www.nass.usda.gov).

Figure B.3: Increase in Yield - Comparison of Breeder's reported Field Trial Data with independent Field Trial Data from the Kentucky Test Stations



Notes: Each of the 17 data points represents a new hybrid for which we observe a direct comparison with an existing plant in the patent document as well as in the Kentucky Performance Test reports. Data on yields were collected by a manual search of the full text of patent documents. Independent test station data from the University of Kentucky (http://www.uky.edu/Ag/GrainCrops/varietytesting.htm).

Figure B.4: Increase in Income - Comparison of Breeder's reported Field Trial Data with independent Field Trial Data from the Kentucky Test Stations



Notes: Each of the 17 data points represents a new hybrid for which we observe a direct comparison with an existing plant in the patent document as well as in the Kentucky Performance Test reports. Data on income per acre were collected by a manual search of the full text of patent documents. Increases in income per acre are also calculated based on independent test station data from the University of Kentucky (http://www.uky.edu/Ag/GrainCrops/varietytesting.htm).